JPRS-JST-90-010
21 FEBRUARY 1990

FOREIGN BROADCAST INFORMATION SERVICE

JPRS Report

Science & Technology

Japan

11TH INTERNATIONAL CONFERENCE ON MAGNET TECHNOLOGY

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

19980129 097

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

DTIC QUALITY INSPECTED 3

JPRS-JST-90-010
21 FEBRUARY 1990

SCIENCE & TECHNOLOGY

JAPAN

11TH INTERNATIONAL CONFERENCE ON MAGNET TECHNOLOGY

43070703 Tsukuba MT-11 in English 28 Aug - 1 Sep 89 pp 8-41, 44-60

[Abstracts of papers presented at the 11th International Conference on Magnet Technology held 28 Aug - 1 Sep 89 in Tsukuba, organized by the Institute of Electrical Engineers of Japan, Association for Promotion of Electrical, Electronic and Information Engineering and the IEEE Tokyo Section]

CONTENTS

AUG. 28 (Mon)

9:30 OPENING REMARKS
Hall H
T. Sekiguchi
MT-11 Conference Chairman

AUG. 28 (Mon) Invited Talk 9:45-10:45

9:45 REVIEW OF MAGNET DEVELOPLENT IN 1980s AND PERSPECTIVES IN COMING 1990s
Hall H
Speaker: H. Desportes
CEN Saclay
Chairman: S. Shimamoto
JAERI

AUG. 28 (Mon) Session JA (oral) 11:00-12:40

HARDRON COLLIDER TEST MAGNETS-1
Room A
Chairman: P. A. Thompson
BNL
Cochairman: T. Shintomi
KEK

11:00 JA-01 FIRST Nb_3Sn WOUND, 1 m LONG SUPERCONDUCTING DIPOLE MODELS FOR LHC BREAK THE 10 T FIELD THRESHOLD, A. Asner and R. Perin, CERN, European Organization for Nuclear Research, Geneva, Switzerland, and S. Wenger and F. Zerobin, ELIN-UNION, Weiz, Austria.

Since two years CERN and ELIN joined in a collaborative effort to develop on an industrial basis a 1 m long, 50 mm bore Nb_3Sn high field dipole model for LHC, with CERN providing the basic know how on the "wind and react" technology and ELIN manufacturing first a mirror test dipole followed by the final dipole magnet. A novel technology has been developed to wind the coils according to the "wind and react" method, the only one to be successfully envisaged in view of the very small bending radii imposed on the Nb_3Sn cables. The excitation coils, which have to withstand a 1'000 K temperature excursion between the 700°C reaction temperature and the operating 4.2 K temperature, are wound of two different 17 mm wide Nb_3Sn cables with an inorganic insulation and exclusively metallic parts, reacted, epoxy impregnated and mounted into the mechanical support structure, consisting of Aℓ-collars, "split" cold iron and outer aluminium alloy cylinder. Design and technology were at first proved in a magnetic mirror dipole device where a full magnet pole was tested in February 1989 : 10.2 T magnetic field was reached after a few quenches at 17.4 kA ; the corresponding overall current densities in the Nb_3Sn cables amounted to 400 A/mm² and 504 A/mm² in the inner and outer layers respectively. The complete magnet has been successfully tested at the beginning of June 1989. A central bore field of 9.5 T has been reached, the maximum field at the Nb_3Sn cable was 10.05 T, and the overall current densities at 15.05 kA excitation current amounted to 346 A/mm² and 436 A/mm².

The achieved results represent world record performances for high field dipole configurations and fully confirm the soundness of the chosen technological options for the "wind and react" method for Nb_3Sn coils.

Together with earlier successful testing of NbTi wound model dipoles at 1.8 K , the CERN high field collider magnet development is now solidly based on two very promising techniques, aiming at the development of 10 m long twin-aperture dipoles for the LHC.

11:20 JA-02 FIRST RESULTS OF THE HIGH-FIELD MAGNET DEVELOPMENT FOR THE LARGE HADRON COLLIDER, A. Asner, D. Hagedorn, F. Haug, D. Leroy, L. Oberli and R. Perin, CERN, European Organization for Nuclear Research, Geneva, Switzerland.

After a brief review of the present state of the R.&.D. programme, the results of the tests of the first two model magnets are described.

The first magnet, designed and built as a joint venture by CERN and ANSALDO Componenti, Italy, is based on the NbTi technology. It was designed for 8 tesla nominal field, but it passed 8.5 tesla without any quench and attained a 9.4 tesla central field. Three test campaigns were performed, two at CERN and one at the CEA, Saclay, Laboratory. No re-training occurred even after having kept the magnet at room temperature for several months. Many discharges at different rates were performed in order to measure quench propagation, heating, etc.. under different conditions, without any damage or degradation occurring to the magnet. This confirmed the merit of the novel "vertically split iron" structure and the reliability of design and construction.

The second magnet, based on the Nb_3Sn wind-and-react technology was designed and built as a joint project of CERN and ELIN-UNION, Austria. Design and technology were at first tested in a magnetic mirror device in which a full magnet pole was tested : 10.2 tesla central field was reached after a few quenches. The complete magnet is expected for May 1989. Encouraging results obtained on high-current cold diode assemblies for magnet protection will be also presented.

11:40 JA-03 INVESTIGATIONS ON QUENCH-HEATER INDUCED QUENCHES IN FULL-LENGTH SSC R&D DIPOLES, A. Devred, SSC Central Design Group, for the SSC Magnet R&D Collaboration (Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley Laboratory, and SSC Central Design Group).

Full-length SSC R&D dipole magnets instrumented with quench heaters and numerous voltage taps have been tested. These voltage taps enable (1) determination of the temperature rise of the conductor during a quench and (2) detailed studies of quench development in the coil. The temperature rise is determined by measuring the resistance of the conductor in the vicinity of the heater and is then plotted versus number of MIITs; observed and calculated temperature-MIITs correlations are in agreement. To study quench development, we first measure the longitudinal quench propagation velocities along the conductor and see how they evolve versus turn. We then study the transverse propagation times from turn to turn and across the copper wedges. The analyses are reproduced on quenches occuring at different currents; they reveal a quench development mechanism that differs from the classical descriptions.

12:00 JA-04 INDUSTRIAL SERIES FABRICATION OF 722 SUPERCONDUCTING DIPOLE- AND SECTUPOLE/QUADRUPOLE-CORRECTION MAGNETS FOR HERA (DESY-HAMBURG) AT HOLEC, H.J. ISRAEL, P.A.M.BRACKE, HOLEC MACHINES & APPARATEN B.V. Ridderkerk, the Netherlands, and C. DAUM, J. GEERINCK, NIKHEF-H, Amsterdam, the Netherlands and P. SCHMUSER, DESY, Hamburg, W. Germany.

After a successfully completed development, in close co-operation between HOLEC, NIKHEF-H and DESY, production of prototypes and pre-series of superferric correction dipole magnets and super conducting sextupole/ quadrupole correction magnets for the arcs of the HERA- protonring, HOLEC has completed industrial series production of 255 s.c. D-magnets and 467 s.c. S/Q-magnets in the summer of 1988. The complete series of both type magnets were delivered according to the agreed time schedule. In fulfilling the required performance these magnets highly exceeds the required technical specification and the very accurate tolerances. Final acceptance shows that only less than 2% of the magnets were below the qualification level which, however, is much higher than the operating current because the magnets have a large safety margin. The paper presents the design and production process as well as a review of the quality control, technical measurements and results on quench behaviour and field quality.

(1) C. Daum, J. Geerinck, H. Möller, R. Heller, P. Schmüser, P.A.M. Bracké, S.C. Correction Coils and Magnets for the HERA Proton Ring, May 1986.
(2) H.J. Israël, Holec production of high accuracy superconducting correction coils and magnets for the HERA proton ring, June 1986.
(3) C. Daum, R. Heller, P. Schmüser, P.A.M. Bracké, Reports at the EPAC-European Particle Accelerator Conference, June 1988.
(4) K.H. Mess, P. Schmüser, Superconducting Accelerator Magnets, January 1989.

12:20 JA-05 PERFORMANCE OF THE SUPERCONDUCTING MAGNETS FOR THE HERA ACCELERATOR, H. Barton, H. Brück, D. Gall, G. Knies, R. Meinke, H. Preißner, P. Schmüser, Bi Yanfang, He Wanliang, Shi Wenlong, Jiao Zhengkuan, Chen Zhuomin, Lin Liangzhen, Krzywinski J., Nesteruk K., Makulski A., Kulka J., Nogiec J., Skotniczny Z., DESY, Hamburg, Germany

Approximately 2500 superconducting magnets and correction coils are needed for the proton ring of the HERA accelerator, presently under construction at the DESY laboratory in Hamburg. The industrial production of these magnets is underway and a large fraction of them have been tested. Test results on leak rates, quench performance and magnetic field quality will be presented. Field distortions due to persistent eddy currents in main and correction coils have been carefully measured and will be compared with calculations of a critical-state model.

AUG. 28 (Mon) Session JB (oral) 11:00-12:40

ENERGY STORAGE-1
Room B

Chairman: H. Kofler
ATF

Cochairman: T. Nitta
Kyoto Univ.

11:00 JB-01 A METHOD FOR THE HIGH ENERGY DENSITY SMES ----- SUPERCONDUCTING MAGNETIC ENERGY STORAGE Y. Mitani and Y. Murakami, Osaka University, Osaka, Japan

The energy density of SMES, $10^7 J/m^3$ for the average magnetic field 5T is rather small compared with that of a battery which is estimated as $10^8 J/m^3$. The energy density of SMES is restricted by the critical current and magnetic field densities, J_c and H_c, respectively, for the conventional superconductors. In the future, we can expect the advent of novel superconductors whose J_c and H_c are far more larger than the conventional ones. In this case, the restricting condition is the mechanical stress which is applied to the superconductors due to the large magnetic field. We propose an integration of solenoids of long axial lengths with small diameters which are closely assembled such that the directions of axial fields of solenoids are reversed each other. The peripheral stress of solenoid is decreased by small diameter of solenoid, since the stress is proportional to the diameter of coil. Furthermore, the leakage field is absorbed due to the ampere turns by the adjacent coils. The calculation results show that the energy density has increased up to 4 or 5 x $10^7 J/m^3$ with B=20T and the mechanical stress is kept in the allowable limits even in this high density of magnetic field.

11:20 JB-02 AN OPTIMAL DESIGN OF SOLENOIDAL SUPERCONDUCTING COIL USED FOR ELECTRICAL POWER SYSTEM STABILIZATION, Y. Mitani and Y. Murakami, Osaka University, Osaka, Japan

Superconducting Magnetic Energy Storage (SMES), which is capable of controlling active and reactive power simultaneously, is an excellent stabilizer for electrical power systems. The effectiveness has been confirmed by numerical and experimental analyses. This paper describes a systematic method to design an optimal solenoidal superconducting coil for the use as a power system stabilizer. The superconducting coil must have an enough energy capacity to charge and discharge power for damping power oscillations. It has been evaluated by several numerical and experimental studies that the necessary energy capacity is 10^7 - 10^8 J, which is rather small compared with the capacity of 10^{10} - 10^{13} J for the load leveling use. In this paper, a design of superconducting coil with high density energy storage is proposed. Energy density of SMES is restricted by the critical current and magnetic field. The proposed optimal design is derived so as to minimize the volume of superconductor under constraints of the current density and the maximum magnetic field. In order to solve the problem systematically the stored energy and the maximum magnetic field are represented by analytic functions of the current density and the shape of magnet. The numerical results show that the optimal volume is proportional to $E^{0.6}$, where E is the stored energy. For further consideration, the mechanical stress applied to the superconductors is evaluated by the finite element method.

11:40 JB-03 DESIRED CAPACITY AND CONTROL STRATEGY OF SMES FOR LOAD CHANGE COMPENSATION AID OF POWER SYSTEM, J. Hasegawa and E. Tanaka, Hokkaido University, Sapporo, Japan

Superconducting magnetic energy storage system (SMES) which has high efficiency and very quick response is expected much not only as a energy storage system but as a power system stabilizer or as a load change compensator. In a power system, outputs of thermal plants cannot be changed so quickly because of the constraints on response rate which are related to thermo-, mechanical dynamics. In addition, the shortage of power plants for load following has been a serious problem. On the other hand, the response time of SMES is less than 100 ms which is much faster than these of conventional power plants, and there is no constraint on response rate of SMES. It is desirable, therefore, to use SMES instead of conventional power plants for load change compensation. In practice, however, there are reasonable MW and MWh capacities of SMES for load change compensation under the economical constraint and desirable operation under the primary usage for load leveling. In this paper, we propose some guidelines to determine the fundamental performance and control strategy of SMES for load change compensation. In the concrete, time constant, MW and MWh capacities of SMES are parameterized and many load change patterns are simulated under several system configurations. The optimal control system for load change compensation with SMES are proposed based on the simulation results.

12:00 JB-04 STUDY OF SMES SYSTEM WITH DC INTERTIE FOR POWER LINE STABILIZATION, H.Okada, T.Ezaki, K.Ogawa, H.Koba, Oita Univ., Oita, F. Irie, Kinki Univ. in Kyushu, Iizuka, M. Takeo, S. Sato, Kyushu Univ., Fukuoka, K. Terazono, Kyushu Electric Power Co.Inc., Fukuoka, M. Takamatsu, Kobe Steel,LTD., Kobe, N. Kawakami, H. Hirano, Toshiba Co., Fuchu, Japan

A new superconducting magnet energy storage (SMES) system proposed by one of the authors for power transmission line stabilization is studied by an experimental model system and computer simulation. It has a SMES in a dc intertie section connected to ac transmission lines via convertors. The distinctive characteristics of this system is that independent stabilization can be made for each ac line and also that the power flow through the dc section can be controlled. For verifying these characteristics we developed a model system consisted of a superconducting pulse magnet(100kJ), PWM convertors, simulated power line system with a generator(10kVA) and a short circuit device to give power line fault. The convertor consists of Graetz bridges with GTO's and is controlled by a pulse width moduration(PWM) with 6 pulses using a microcomputer. Variables for the control are active powers(PA, PB) and reactive powers(QA, QB) for each power line of both side(A, B), where PA-PB are accumulated in the SMES coil. Experiments by the model system have been made. An experiment of power flow control was made for the dc intertie SMES system connected in parallel with a model line, which proved to be successful. Line fault experiments were made, in which power fluctuation in one side caused by a short circuit between line and earth keeping the power flow constant was very much supressed by this system. A numerical analysis has been made for this case using some approximation. The results explains qualitatively the feature of those waveforms.

12:20 JB-05 ON THE MULTIPLE-RING COIL SYSTEM FOR SMES, T. Ezaki, Oita University, Oita, Japan and F. Irie, Kyushu Engineering Department, Kinki University, Iizuka, Japan

Intermediate scale SMES(~100GJ) which is located near urban area might be suitable for the land as Japan where wide site for large scale one(~10^4GJ) is rather difficult to find. Required conditions for such SMES are at first that the hoop stress applied on the coil conductor should be small, because rigid bed rock is not always available at urban area. Then next condition is that the plottage which includes area for reducing leakage magnetic field should be small. Conventional low aspect-ratio solenoid-coil have large leakage magnetic field and large hoop stress on those coils, though it has the minimum quantity of conductor.

In this paper, we propose a new coil system named multiple-ring coil system for the intermediate scale SMES. This system consists of concentric multiple low aspect-ratio coils in which the direction of current in each coil is opposit to those of neighboring coils. This system has higher storage energy than that of a single solenoid for the same plottage by the utilization of inner space of a single solenoid, only at the expense of a conductor quantity. It also has relatively low hoop stress as well as low leakage field due to the cancellation of field from each coil, both of which makes the introduction of this system into suburban area easier.

Ampare turns of the coils are optimized to minimize the hoop stress of the system. As a result, it is shown that the hoop force of this system is 1/2 of that of the single solenoid coil, whereas the radius is 5/6 of that of the latter of 30mϕ for the case where the stored energy is 100GJ, muximum magnetic field being 10T. The leakage field is reduced to 1/10 of that of the single solenoid for the same condition.

AUG. 28 (Mon) Session JC (poster) 11:00-12:40

I HIGH Tc SUPERCONDUCTORS-1
II POWER APPLICATIONS-1
III INSTRUMENTATION AND MEASUREMENTS-1
Room P1 and P2

Chairman: H. Jones
Oxford Univ.

Cochairman: K. Noto
Iwate Univ.

JC-01 SUPERCONDUCTING PROPERTIES OF Bi(Pb)-Sr-Ca-CU-O OXIDES PREPARED BY AN INTERMEDIATE REPRESS-PROCESSING, T.Asano, Y.Tanaka, M.Fukutomi, K.Jikihara,and H.Maeda, National Research Institute for Metals,Tsukuba Labs, Ibaraki, Japan Remarkable improvements in the critical current density, of the Bi(Pb)-Sr-Ca-Cu-O sintered specimens have been achieved by applying a modified combination process of heat treatment and pressing. Disc-shaped specimens were pressed uniaxially at room temperature after initial sintering treatment and followed by a subsequent sintering at the same temperature. This intermediate pressing method has produced a dense and highly oriented microstructure with an enhanced formation of the high-Tc phase and a remarkably large critical current density, Jc. Effects of the heat treatment condition before and after the intermediate pressing on the microstructure and Jc property have been studied. The Jc properties in the magnetic fields at temperatures of liquid helium and around liquid nitrogen will be discussed along with AC susceptibility and the magnetic flux pinning for these specimens.

JC-02 IMPROVEMENTS IN SUPERCONDUCTING CHARACTERISTICS OF Bi-(Pb)-Sr-Ca-Cu-O SUPERCONDUCTORS, H.Sekine, K.Inoue and H.Maeda, National Research Institute for Metals, Ibaraki, Japan, and K.Numata, Advanced Technology Research Center, Mitsubishi Heavy Industries, LTD., Yokohama, Japan, The Bi-(Pb)-Sr-Ca-Cu-O superconductor has been fabricated into tapes without sheath and into multifilamentary wires and tapes with Ag sheath. Superconducting characteristics, magnetic field dependence of the critical current, possibility of forming superconduting phase in a long wire, morphology, effects of compacting, effects of c-axis alignment and so on have been studied. Tape specimens prepared by combination and repetition of cold work (or cold press) and of sintering showed critical current density, J_c, as high as 5×10^3 A/cm^2 at 77K with good reproducivility and reliability, although these specimens are sufficiently thick (0.5-1.0 mm). For these tape specimens (with Cu sheath), sintering and J_c measurement were performed after the Cu sheath was removed. X-ray analysis showed that most of these tape specimens consist purely of high-T_c phase (107K). In these specimens, c axis tends to align well. This c axis alignment may be a cause of the enhancement in J_c. On the other hand, the tape specimens cold-worked and sintered only once (not repeated) showed J_c as small as only 10^2A/cm^2. They showed no sign of the c axis alignment. Measurements of magnetization curves have indicated that flux pinning force almost vanishes at the magnetic field above 0.2T at 77K due to the mechanism of flux creap, while strong flux pinning force exists even at a very high magnetic field (17T, for example) at 4.2K. Tape specimens fabricated by the repetition of cold work and sintering showed J_c of 3000A/cm^2 at 17T at 4.2K.

JC-03 ACCOUNTS OF CHARACTERISTICS OF TRANSITION INTO NORMAL STATE OF SUPERCONDUCTING SOLENOID ON BASE OF HIGH TEMPERATURE SUPERCONDUCTORS, N.V.Krivolutskaya, P.N.Lebedev Physical Institute of the AS USSR, Moscow
The discovery of high temperature superconductors and intensive developments in this branch of science touched on possibility of using these superconductors in large scale technical devices instead of traditional ones. On the assumption that difficultes for build-up of current carring elements will be precluded we studied outcomes of unplaned transition into normal state of magnet system consisted of superconducting solenoid with whole winding. It also has been analyzed of possibilities of protection for the magnet system by traditional sections with shunting low ohms resistors. It was found that for unprotected solenoids in case of arising of normal zone all storage energy is giving off in little volume, the heating temperature of that is increasing up to thouthands of degree K. It has been shown that using of Cu like as stabilyser of current carring element on base of $YBa_2Cu_3O_7$ is unenough. In case of protected solenoids increasing of operating current up to 0,95 of critical value don't give rise to realization of "electromagnetic avalanch" regim in system. Increasing of current in sections is imperceptible and heating don't decreases essentially. So it is necessary to use other methods of protection.

JC-04 CRITICAL CURRENT DENSITY AND MICROSTRUCTURE OF STOICHIOMETRIC YBCO SUPERCONDUCTORS, A. Nagata, Mining College, Akita University, Akita, Japan, M. Oikawa and O. Izumi, Institute for Materials Research, Tohoku University, Sendai, Japan
Stoichiometric $YBa_2Cu_3O_\delta$ superconductors were sintered for various period at 890°-930°C by using Y_2O_3, $BaCO_3$ and CuO (99.99%-purity). Specific density, critical temperature (T_c), critical current density (J_c) at 77K and 0T and at 4.2K in magnetic fields up to 10T and grain size of them were measured. Specific density increased with increasing sintering temperature and time.
T_c on set was almost independent of sintering condition but T_c off set increased with sintering time and temperature just like specific density. J_c (77K,0T), first, increased with increasing time, got maximum and then decreased with time at all sintering temperatures. Grain size of samples increased slightly for short sintering period and then markedly. The first increase in J_c is considered to be corresponded to the improvement of sintering among grains. The decrease in J_c is corresponded to grain growth and J_c-grain size relationship can be drawn a master curve even if the sintering temperature is varied. The similar relationship was obtained for J_c at 4.2K in the magnetic field of 1T. In order to elucidate this relationship, X-ray diffraction, optical microstructure and SEM observations, EDX analysis at grain boundaries and oxygen analysis were carried out for typical samples with 3 different grain size. However, no specific differences could be detected in these samples. It might be, therefore, concluded that the decrease in J_c with increasing grain size is closely related to the pinning sites which are correlated to grain growth and grain size.

JC-05 A.C.MAGNETIC FIELD PENETRATION INTO SUPERCONDUCTING SHIELDS OF $YBa_2Cu_3O_7$ CERAMICS AND Nb-Ti FOIL. Yu.A.Bashkirov, K.Sh.Lutidze,L.S. Fleishman, I.V.Yakimetz. Krzhizhanovsky Power Engineering Institute, Moscow, USSR.
This paper concerns a study on the a.c. magnetic field penetration into hollow cylindrical superconducting shields that can be used for magnetic flux switching in electric engineering devices. The processes of field penetration into shields made of $YBa_2Cu_3O_7$ high T_c ceramics and Nb-Ti foil were found to vary in character. With ceramics, the field gradually penetrates the hollow of the shield with an increasing amplitude, while the time dependence of the field in the hollow exhibits strong anharmonicity. Such behavior is due to the weak link character of the intergrain shielding currents. Suppressing the weak links, the magnetic field brings about shielding circuit breakdown. The critical current drop under applied field causes higher a.c. field harmonics to appear in the hollow, while its low value and and high heat capacity of the ceramics ensure thermomagnetic stability. With shields made of Nb-Ti foil, spontaneous magnetic field penetration is observed at a certain field value, which is the result of theirlow adiabatic stability, particularly in a.c. fields. The heat released during flux jump has partial character. In higher fields,the Nb-Ti foil shield reaches a stable resistive state characterized by partial magnetic field penetration.

JC-06 IMPROVEMENT IN THE CRITICAL CURRENT DENSITY BY STRENGTHENING SILVER SHELLS IN HIGH-Tc SUPERCONDUCTING Y-Ba-Cu-O WIRES, J. Chikaba, Faculty of Engineering, Kinki University, Iizuka, Japan

High-Tc superconducting oxide wires covered silver(Ag) shells can be easily made by the usual solid phase reaction method. The critical current density Jc, however, is lower than that of bulk samples at present. It is necessary for the improvement in Jc that weak links between grain boundaries should be reduced by realizing the fine ceramics.

According as the diameter of the wire became thin in rolling and swaging processes, Jc in general could be improved sharply. But when the diameter of the wire became thinner than a certain extent, Jc rather began to degrade. The fact suggests that cracks come into existence in the Ag shell because of the brittleness and fatigue through tens of rolling processes.

As the result of this work so far, it has been elucidated that, of course, cracks grow in the ceramic core due to a thermal contraction for the sintering process, but the crack in the Ag shell plays a certain villain because of decreasing the successful high density.

In this paper, the improvement in Jc of superconducting Y-Ba-Cu-O wires was made a trial by strengthening the Ag shell where stainless steel nets or Ni-Cr alloy nets were sandwiched in between double Ag shells for the reinforcement. The composite wires were rolled and swaged from 6 mm diam to 0.5 mm diam and sintered at 910°C/5-20 hr. Measurements of Jc-H characteristics were performed under bending strain after sintering.

The value of Jc in the double layered Ag shell with stainless steel nets was three times as large as the value in the wire without the reinforcement. More than 2000 A/cm' Jc, the degradation of Jc by the bending strain was fairly small.

JC-07 ENHANCEMENT OF Tc Y-Ba-Cu-O THIN FILMS AFTER PROTON IRRADIATION, A.A. Nikonov, G.V. Sotnikov, A.S. Tokarev, Kurchatov Institute of Atomic Energy, Moscow, USSR

The influence of 3.9 MeV-proton irradiation on Tc of YBCO thin films was investigated. The irradiation was carried out at different temperatures in oxygen atmosphere. In contrary to the irradiation in vacuum conditions, where the linear decreasing of Tc versus fluence was obtained, the irradiation in oxygen atmosphere shows that there are three intervals in the full fluence range where the character of Tc decreasing changes drastically. At low fluencies the rate of Tc decreasing is less than corresponding value obtained after the irradiation in vacuum. At high fluencies the Tc degradation rate increases considerably. At medium fluencies the changing of SC properties acquires a very unstable character. After some doses we observed substantial increasing of Tc determining either from x"(T) peak position or from appearance of diamagnetic signal. We suggest that the observing enhancement of Tc can be the result of penetration in the YBCO film of additional amount of oxygen from outer gaseous medium and subsequent redistribution of the oxygen atoms among vacant positions in the crystal. This process can be reinforced by the radiation enhanced diffusion. In addition to the Tc increase the considerable growth of the peak's height on the x"(T) curve was observed. The creation of resistive paths for current can be responsible for that.

JC-08 THE GRAIN BOUNDARIES OF HIGH-T_c COPPER OXIDES AND A-15 COMPOUNDS, M. Akinaga, Department of Physics, Fukuoka University of Education, Fukuoka, Japan

The discovery of extraordinarily high superconducting trandition temperature in perovskite copper oxides is a most great surprise in condensed matter physics. These materials and the prospect for future discoveries have kindled wide interest in superconductivity and superconducting materials research. Especially, this discovery have had a great impact on the application in many technical field, for example, on the technology of superconducting magnet. However, the critical current and magnetic properties of most bulk and tape samples of these new high-T_c superconductors studied to date appear to be dominated by their gross granular structure. This can lead to low and magnetic-field-dependent critical currents because of weak Josephson-like coupling between grains. Then the study of grain boundaries in these materials is very important for the progress of the magnet technology. It is also necessary for the investigation of the new superconductivity through the phenomena due to Josephson effect which occur there. We have investigated the I-V characteristics for lines which crosse grain boundaries in $YBa_2Cu_3O_{7-\delta}$ and Bi-compound films deposited by RF-magnetron sputtering, in the wide temperature range. They showed the typical I-V curves due to superconducting weak link with excess current which were completely same as those for short weak link in tin variable-thickness microbridge. We have compared them with the results of traditional A-15 Nb_3Ge and other films deposited by RF-sputtering. The films were analyzed by SEM, EPMA and EDS.

JC-09 PREPARATION OF AS-DEPOSITED SUPERCONDUCTING Y-Ba-Cu-O FILMS BY DC MAGNETRON SPUTTERING FROM SINGLE TARGET, M. Suzuki, T. Uchiyama and K. Takahashi, Dept. of Elect. Eng., Tohoku University, Sendai 980, Japan, Japan Fine Ceramics Co., Ltd. Sendai 981-31, Japan

We have prepared as-deposited superconducting films of Y-Ba-Cu-O on the cleaved surface and the polished one of MgO single crystal maintained at 670-770 °C in an argon-oxygen atmosphere by dc magnetron sputtering. Used targets are disks of 50 mm in diameter and 4 mm in thickness and have been prepared by a conventional sintering technique. Target compositions are Y:Ba:Cu=1:1.8:3, 1:2:3, 1:2:3.3, 1:2:3.6 and 1:2:4.5. The sputtering argon-oxygen gas pressure P_{Ar+O2} of 300 mTorr have been mainly tested. The oxygen partial pressure has been varied from 3 to 20 mTorr. The distance between target and substrate is 20 mm and the input power 40 W. The deposition rate ranges from 1.8 to 3.0 nm/min and has been rapidly reduced by increasing the oxygen pressure. In the case of depositions at P_{Ar+O2} lower than 200 mTorr, resputtering effects become very strong and little depositions on the substrate have occurred.

As-deposited superconducting films with $T_c(R=0)>77$ K have been made by carrying out the heat treatment of 1 h at 550 °C in an oxygen pressure of 20 Torr during cooling after deposition except for deposition runs from a target with Y:Ba:Cu=1:2:4.5. These are polycrystalline films of the perovskite phase. The maximum T_c of 81.5 K has been observed in a film sputtered from a target with Y:Ba:Cu=1:1.8:3 close to stoichiometry. Films deposited on the polished surface show appreciably high critical current density J_c and their J_c values at 4.2 K reach 3×10^5 A/cm^2 at 13 T.

JC-10 PREPARATION OF SUPERCONDUCTING $YBa_2Cu_3O_{7-x}$ THIN FILM ON METAL SUBSTRATE BY CHEMICAL VAPOR DEPOSITION PROCESS, S. Aoki, T. Yamaguchi, N. Sadakata and O. Kohno, Tokyo Laboratory, Fujikura Ltd., Tokyo, Japan

Application of the high-T_c superconducting materials for conductor is promising because of the great advantages of operation at liquid nitrogen temperature. Though the materials has some intrinsic properties like anisotropic current flow and weak links at grain boundaries which may greatly reduce the current carrying capacity especially under magnetic field. In order to conquer the problems, thin film fabricating methods are attractive because highly oriented or even single-crystalline films could be obtained. In particular, chemical vapor deposition process is a promising candidate as a conductor fabrication because its growing rate is much larger than the other thin film processes. Superconducting $YBa_2Cu_3O_{7-x}$ thin films have been prepared by chemical vapor deposition using beta-diketonate chelates of Y, Ba and Cu on single-crystalline $SrTiO_3$ substrates and metal substrates. As-deposited film showed poor superconducting properties, and consequent annealing raised the zero-resistivity temperature to 85K. According to an X-ray diffraction patterns, the orthorhombic crystal structure has been confirmed. The growth rate of the films were found to be about 30 microns per hour or more. The morphology indicated that it was consisted of polycrystalline grains. Dense structure was observed and voids were rarely recognized in the film. This study has been collaborated with Chubu Electric Power Co., Inc.

JC-11 CHARACTERISTICS AND SUPERCONDUCTIVITY OF Y-BA-CU-O THIN FILM ON METAL SUBSTRATE BY SPUTTERING WITH INTERMEDIATE BUFFER LAYER, Y. Iijima, H. Hayakawa, N. sadakata and O. Kohno, Tokyo Laboratory, Fujikura Ltd., Tokyo, Japan

For the application of the high temperature superconducting materials, it is of great importance to fabricate composites on long flexible substrate without diminishing excellent superconducting performance. Substrates of certain metal alloy are quite favorable due to their flexibility and thermal properties for a conductor. Meanwhile, films of well-aligned grains with preferred orientation which yield high critical current density under magnetic field have been reported by using thin film processing. Sputtering is one promising procedure to fabricate such thin films with good superconductivity, however, the thin layer of the films on the substrate may be contaminated by the diffused elements from the metal alloy during the deposition. In order to eliminate the degradation of the films, placing intermediate buffer layers which may act diffusion barrier between the film and the substrate is effective as a practical superconductor. In this paper, we discuss the effect of the existence of intermediate buffer layer of $SrTiO_3$ on metal substrate, mainly nickel based alloy. The buffer layers and Y-Ba-Cu-O thin film were prepared by sputtering. The substrate was heated 550-700°C during the deposition. The microscopic morphology of the layers and distribution of the element at the interfaces and other characteristics are investigated. This research has been collaborated with Chubu Electric Power Co., Inc.

JC-12 25 KV SUPERCONDUCTING FAULT CURRENT LIMITER. A. Février, T. Verhaege, J.P. Tavergnier, Laboratoires de Marcoussis, 91460 Marcoussis, Y. Laumond, M. Bekhaled, Alsthom - DEA, 90018 Belfort , M. Collet, V.D. Pham, Alsthom - DAT, 69611 Villeurbanne - (FRANCE).

Our technological progress in the field of superconductivity over the last ten years made possible the manufacture of industrial lengths of conductors, consisting of NbTi ultra-fine filaments, embedded in a Cu-30 wt % Ni matrix ; 50 Hz losses are greatly reduced, and the electrical resistance beyond the critical current is very large. Such conductors offer numerous new perspectives, through which the design of electrotechnical machines could be reconsidered.This paper describes the main features of a 50 Hz single-phase fault current limiter, constructed in our laboratories which present some electrical and cryogenic properties : S-N transition limitating the fault current to a value a few percent above the nominal current, within a few µs high voltage insulation capabilities, moderate cryogenic losses during steady state and in transient conditions... .

JC-13 SWITCH OF MAGNETIC FIELD BY ROTATING SUPERCONDUCTING SHIELD, K. Takahata, S. Nishijima and T. Okada, ISIR Osaka University, Ibaraki, Osaka, Japan

The switch of magnetic field up to 1 T has been developed using tubular superconducting magnetic shield. The switch is operated by rotating the shield in the magnetic field. The shield was constructed by windings using NbTi multifilamentary composite wires and impregnated entirely with the Wood's metal. The wires were wound spirally at angles of +45 and -45 degree with respect to the axis. The uniform transverse field was applied using a superconducting split magnet. The switching ability was examined with rotating the shield around the axis. The experimental results indicate that the field can be switched on and off by rotating the shield because the shielding ability shows anisotropy. When the switch was off, the field at the center of the switch was less than 1 mT at the applied field up to 1 T. The present technique will be applicable to accelerators, HGMS and so on. This study will examine the applicability of the rotating superconducting shield to the magnetic field switch. The field distribution and electromagnetic force in the shield will also be discussed.

*This work is partly supported by Grant in Aid for Scientific Research No. 63050033, Ministry of Education in Japan.

JC-14 DEVELOPMENT OF THE THERMAL SUPERCONDUCTING SWITCH AND RESEARCH ON ITS CLOSED PROCESS, Lin Yubao, Chen Yuelian, Lin Liangzhen, Institute of Electrical Engineering , Academia Sinica. A series of thermal superconducting switches for the superconducting magnet systems in 'persistent mode' have been developed at Institute of Electrical Engineering, the Chinese Academy of Sciences. The maximal current is up to 300 A(at 0.8T). The multifilamentary NbTi wire with Cu(70)Ni(30) matrix and seven cabled multifilamentary NbTi wires with Cu-Ni matrix are used for the superconducting switches. Two superconducting switches have been made and operated successfully, one for a superconducting magnet system for a large format electro-camera and another for a high field superconducting magnet. Moreover , the superconducting switch using the multifilamentary Nb_3Sn wire with bronze matrix has been developed. The researches on the closed process between the superconducting switch and magnet and some key problems in the process have been engaged. The experiments show that the maximal closed current of the superconducting switch is proportional to the reciprocal of the ripple factor of the DC. voltage source. The quantitative relation between them was got from the experiments below 50 A of the closed current. The maximal closed current of superconducting switch is the higher, the lower the rate of decrease of the source current . The development of the thermal superconducting switch and the experimental results have been presented in this paper.

JC-15 OPERATION OF A NEW-TYPE RECTIFIER FLUXPUMP WITH SATURABLE CORE TRANSFORMER, K. Funayama, T. Isono, M. Suzuki, M. Sato, T. Anayama, Dept. of Elect. Eng., Tohoku University, Sendai 980, Japan.

A new-type transformer-rectifier fluxpump has been constructed and tested. This fluxspump is composed of power input and control units, a superconducting transformer with an iron core, two superconducting switches and a load coil. High efficiency and constant rate of increase in load current have been accomplished by using a saturable core transformer whose iron core has a nearly rectangular hysteresis loop.

The operation of fluxpunps is principally divided into the pumping region and the commutation one. In the pumping region of the present fluxpump the superconducting transformer whose iron core has been driven between one saturated magnetization state and the other indicating high permeability, supplies high current in the secondary circuit. Moreover, the flux change within the core is simply limited by its saturation magnetization, so that the rate of change in the load current may be maintained constant during charging or discharging. In the commutation region the secondary coil inductance of the transformer has been highly reduced. As a result, the loss and the depression in the load current, which are caused by commutation has been considerably decreased using an inductive commutation technique.

The present fluxpump has energized 100A to the load coil of 1.1H for 940 second with an operating frequency of 0.2Hz. The primary current is controlled between 0.05 and 3.05A depending on the load current. The energy efficiency involved in operation is estimated to be in excess of 90% .

JC-16 **THEORY AND VERIFICATION TESTS OF THE Nb-Ti RIBBON THERMALLY CONTROLLED SWITCH FOR LARGE CURRENT-LOW VOLTAGE 50 Hz APPLICATIONS, N.V. Markovsky, O.A. Shevchenko, I. Hlásnik, J.Kokavec, Basic Laboratory for Technical Applications of Superconductivity of the Electro-Physical Research Center, Slovak Academy of Sciences, Bratislava, Czechoslovakia**

Theoretical analysis of the influence of different design parameters such as the thickness of superconductor, of heater and of insulation material as well as the bath and working temperature on the main characteristics i.e. on the activation and recovery time constants and the losses of a thermally controlled superconducting switch is presented. It reveals the possibility to increase the repetition frequency of such switch in the range of the industrial 50-60 Hz frequency. Verification tests of a thermally controlled switch made from 20 µm thick and 10 mm wide Nb-Ti ribbon in a half wave rectifier mode at 50 Hz have been made. Maximum current amplitude of 306 A at effective resistance less than 0.1 µΩ in the superconducting half period as well as maximum voltage amplitude of 0.57 V at effective resistance of about 40 mΩ in the resistive state half period have been attained. These results are of great hopes in using superconducting rectifiers with such thermally controlled switches for powering superconducting magnets. Further improvements and measurements are now being made and their results will be presented too.

JC-17 **BASIC TEST OF A 3-PHASE SUPERCONDUCTING FAULT CURRENT LIMITING REACTOR***

H. Kado, T. Ishigohka
Seikei University
Tokyo, Japan

A 3-phase superconducting fault current limiting reactor (SCFCLR) is fabricated, and some experiments are carried out. The fundamental behavior of this reactor is confirmed. The SCFCLR has three superconducting windings with the same number of turns wound on an iron core. The rating of SCFCLR is 200V, 10A. Two SCFCLRs are inserted in the sending and the receiving ends of the model power-transmission line.

The experimental results are summed up as follows;

1)for balanced 3-phase current, the SCFCLR exhibits very small impedance drop,
2)in the case of single-line-to-ground fault, the fault current is limited to very small value by the large zero-phase-sequence reactance of the SCFCLR,
3)in the case 2), superconducting windings do not quench,
4)in the case of two-line-to-ground fault or three-phase short circuit, the SCFCLR quenches, and the short circuit current is limited by the normal conducting resistance of the winding.

In conclusion, it is experimentally confirmed that the SCFCLR can limit the fault current in all the fault conditions.

*Supported by Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture of Japan.

JC-18 DEVELOPMENT OF Nb_3Sn PERSISTENT CURRENT SWITCH, M. Urata, H. Maeda, M. Tanaka, S. Murase, *Y. Oda, *S. Nakamura. Toshiba R & D Center, 4-1, Ukishima, Kawasaki, Kanagawa, *Showa Electric Wire and Cable Co.ltd, 2 1 1 Odasakae, Kawasaki, Kanagawa, Japan. Nb_3Sn persistent current switch (PCS) is a promising device which improves the stability of persistent current mode systems such as MRI or magnetically levitated train, as its temperature margin is larger than a conventional NbTi PCS. This paper presents the fabrication process and the test results of such a Nb_3Sn PCS, developed at Toshiba R & D Center. The fabrication process is as follows: Conductor is a multi filamentary Nb tube processed Nb_3Sn with Cu 10w%Ni matrix. The conductor diameter is 0.87 mm, while the matrix to superconductor ratio is 1.0. The switch is 112 mm in outer diameter and 110 mm in height. Quench current of the switch is degraded in low field region(< 1.5 T), which is remarkably improved for a smaller diameter conductor made from the same billet. For the 0.87 mm conductor, flux jumping is observed in a magnetization curve in the low field. Nb_3Sn thickness in Nb tube for the conductor, 4 um, is near the calculated minimum thickness for flux jumping to occur. Thus, the degaradation is supposed to be caused by the magnetic instability of the conductor in the low field.

JC-19 **QUENCH RECOVERY TEST OF 3-WINDING SUPERCONDUCTING TRANSFORMER WITH AN AUXILIARY WINDING ONLY IN LOW VOLTAGE*** SIDE**, H.Kamijo* T.Ishigohka* N.Mizukami* M.Yamamoto**, *Seikei University, Musashino JAPAN, **Takushoku University, Hachioji JAPAN

Superconducting transformers have to be protected against any power system faults including sudden short-circuit faults at transmission line. However, it is impractical to design a superconducting transformer (SCT) not to quench for any power system short-circuit faults because of the excessive winding loss at normal operation. So far, the auxiliary coils are introduced both to the high and the low voltage side of the transformer. In this case, when the main windings quenched, the two auxiliary windings carry the load current. Then the transformer can operate continuously. However, it is rather complicated to install two auxiliary windings. Particularly, the preparation of the one in the high voltage side is highly troublesome because of the insulation requirement. Therefore, the authors proposed to introduce the auxiliary winding only in the low voltage side. In this case, the possible maximum fault current can be reduced considerably by the high leakage impedance of the auxiliary winding. So, the current capacity of the high voltage winding should be designed to fit only for this suppressed fault current. The authors fabricated a samll experimental SCT of this type, and carried out some transient experiments. Through the experiments, it becomes clear that 1)the low voltage main winding should be isolated from the circuit after its quench, 2)in this case, the recovering time of the quenched main winding to superconducting state is considerably small.

***Supported by Grant-in-Aid for Co-operative Research of the Ministry of Education, science and Culture of Japan.

JC-20 SYSTEMATIC EFFECT OF RANDOM ENVIRONMENTS IN AMORPHOUS METALLIC ALLOYS/A SYSTEM HIERARCHIAL MODEL (SUPER CONDUCTING, MAGNETIC BEHAVIOUR), V.P.Kapur, University of Roorkee, Roorkee, India, and Nikhil Kapoor, Usha Amorphous Metals Limited, Udyog Vihar, Gurgaon, India.

High degree of stochastic environments to which alloying elements are subjected to under supercooling metastable conditions, it behaves as an ergodic system. Failure to explain superconducting magnetic and other anomalous behaviour, is frustrating the research effort. Systematic effect of random signals (noise) will influence the density of states and absorption, in disordered molecular systems. A disordered excitonic system purturbed by the Gaus Markov noise approximates, the exciton-phonon interaction. Magnetic and structural properties of rapidly quenched IronBoron metallic glasses exhibit two kind of stochastic arrangement (cluster formation) and interface between them. An analytical structure, when corrected for 'systematic effect of random functions conforms and reproduce experimental results vis-a-vis density, variation of small angle, scattering and radial distribution function of atomic distances. The effect of moving averages is taken care of by the choice on system alternatives, which affords the possibility to match the hierarchies to the prevailing environments. The model is validated with practical data. Signal processing has been used to interpret the results.

JC-21 MAGNETIC FIELD MEASUREMENT OF THE MEDIUM RESOLUTION SPECTROMETER (MRS) DIPOLE MAGNET, B.L. Weintraub, S.F. Archuletta, M.G. Mays, Los Alamos National Laboratory, Los Alamos, New Mexico, USA

The Medium Resolution Spectrometer (MRS) dipole magnet at LANL is to be used in studying p-nucleus and n-nucleus reactions in medium energy physics. It has a magnetic element configuration of QD(-D). In this design, two dipole magnets were combined to share a common return yoke. The beam trajectory is s-shaped, hence the early installation of a vacuum chamber. This unusual geometry prohibits use of normal measuring techniques, posing a challenge in mapping the magnetic field. The long distance and unusual geometry prohibits use of a normal system where the measurement probes are swept through the magnet in a continuous motion, from entrance of the first dipole to exit of the second dipole. The measurement must be performed in two independent set-ups, with sufficient overlap to normalize the data with respect to a common coordinate system. At 100 tons, the magnet is virtually immovable, requiring that the mapper and data acquisition equipment be mobile. Its large size has necessitated designing a new computer-controlled positioning system, as well as upgrading the data acquisition software. Existing equipment was adapted, where possible, resulting in relatively uncomplicated solutions. Expected resolution from this new system is 1 part in 10^4.The MRS magnet is scheduled for measurement and installation in time for the upcoming run cycle. This poster will describe upgrades to existing equipment, newly-designed equipment, and the actual mapping of the MRS magnet.

JC-22 A MICROCOMPUTER CONTROLLED, SELF-CONTAINED FIELD MEASUREMENT AND ANALYSIS SYSTEM, C. Haddock(2), G. Smith, J.S.C. McKee, Department of Physics, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada.

Current accelerator projects will involve the construction and field measurement of up to ten thousand magnets. A statistical analysis has shown that in order to optimize the performance of an accelerator it will be necessary to measure the parameters of field strength, field uniformity and harmonic content of every magnet. If the measurements are performed at the construction site, the magnets which do not meet the required specifications can be repaired immediately. This paper describes a self-contained field measurement and analysis system, based on an IBM microcomputer, which performs all the remote control, data acquisition and data analysis functions automatically. The system is of low cost such that each manufacturer could provide field parameters on each magnet as it is completed thus avoiding a logistical problem at the accelerator site.

JC-23 WIRELESS CRYOGENIC QUARTZ THERMOMETER WITH HIGH RESOLUTION (0.01K) FROM 400 K TO 4.2 K WITHOUT MAGNETIC FIELD DEPENDENCE, K.Agatsuma, F. Uchiyama, K. Tukamoto, T. Ohara, H. Tateishi, Y. Nobue, S. Ishigami*, M. Sato* and H. Sugimoto*, Electrotechnical Laboratory, Tsukuba, Ibaraki, JAPAN, *Tokyo Denpa Co. Ltd., 5-6-11 chyuoh, Ohtaku, Tokyo,

We have found a quartz crystal resonator to show really good properties as a cryogenic thermometer with high resolution without magnetic field dependence (up to 10 Tesla at 4.2K) covering the wide range from 400 K to 4.2 K. The quartz crystal resonator sliced either in the "LC" cut or in the "YS" cut from high quality synthetic single crystal quartz was tested and calibrated by using a Platinum resistor, a thermocouple and a Germanium resistor under thickness-shear mode of operation through either extended cable connection or radio echo telemetric transmission from the resonators. Temperature reproducibility is excellent within 0.4 ppm maximum (0.2 ppm typical; 0.002K) when thermally shocked between a room temperature and the liquid nitrogen temperature. After the deposition of silver electrodes on the surfaces of the quartz wafer, it is supported by nickel silver sheet springs in a small wafer case which is hermetically sealed in helium atmosphere with a cold welding. The quartz resonator itself dissipates extremely small power. The resonant frequency non-linearly reduces from about 10.7 MHz(1kHz/K) at 300 k to about 10.54 MHz(120Hz/K) at 4.2 k according to decline of the resonator's temperature. The experimental results is presented in detail.

JC-24 CHANGE OF OPTIMAL OGMS CHARACTERISTICS IN USING CURRENT VARIABLE DENSITY SEPARATOR FOR MAGNETIC SYSTEM CURRENT COILS, V.K.Fedorov, I.V.Kurchatov Institute of Atomic Energy, USSR

In the present work, using the plane OGMS with rectangular-cross-section linear conductors, by way of example, an estimate has been made of the change in characteristics of optimal OGMS (the magnetic system dimensions Δ , β , γ ; the separator productivity P_o per unit plane of the magnetic system; the selectivity $S\ell_o$ /1/) whose current density over the conductor cross section changes by the linear law from the centre of the conductor cross section to its boundary. Calculations have been made for separators with wet and dry separation processes with optimization over max P_o, depending on the design factor q /2/ in the range $1 \leq q \leq 10^3$ and on the parameter of the current density drop by the linear law, $n = J_b/J_c$, in the range $0.2 \leq n \leq 1$, where J_b and J_c are, correspondingly, the current densities at the boundary and at the centre of the conductor cross section. The increase of the productivity P_o, the decrease of the magnetic system thickness Δ , the increase of the current conductor width β , the practical conservation of the layout interval γ of conductors and of the selectivity $S\ell_o$ with decreasing n - all these are general for the considered versions of the current density drop and separation processes.

1. T.Yu.Dmitrievskaya et al., Selectivity of VGMS, Proc. of MT-9 Conf., 1985.
2. P.A.Cheremnykh et al., An Analysis of Axial-Disk VGMS Characteristics, Proc. of MT-8 Conf., 1983.

JC-25 A MEASUREMENT OF JOINT RESISTANCE BETWEEN MULTIFILAMENTARY WIRES, T. Tominaka and H. Tomeoku, *Hitachi Research Laboratory, Hitachi, Ltd., Ibaraki, Japan*

A technique for measuring the joint resistance was developed, using the SQUID voltmeter. The joint was used to close a small loop of multifilamentary wire. On this measurement, the current was induced in the loop, and its decay was observed by means of the field-decay measurement technique. In addition, the small voltage between both ends of joint was observed by the SQUID voltmeter. On a soldered joint of superconducting loop, the exponential dependence on the time was observed for both current and voltage decays with almost same time constants of decay. Presently, the voltage sensitivity of ~ 2×10^{-11} V has been obtained on our apparatus. Now, we are trying to improve the voltage sensitivity. Due to the application of SQUID to the measurement of joint resistance, the detail evaluation of superconducting joints become possible. As a result, we do not need to estimate the inductance of the superconducting loop, and we can measure the resistance of one joint among the several joints included in one superconducting loop.

JC-26 EARLY QUENCH DETECTION AND DIAGNOSIS OF SUPERCONDUCTING MAGNETS USING ULTRASONIC WAVE,**** A. Ninomiya*, K. Sakaniwa**, T. Ishigohka***, N. Mizukami* H. Toyoda**, Y. Higo**, H. Inaba

* Seikei University, Musashino-shi, Japan
** Tokyo Institute of Technology, Yokohama-City, Japan
*** Fuji Ceramics co.,ltd, Fujinomiya-City, Japan

We have been studying a new method to detect a quench of a superconducting magnet at its early stage. The method detects a change of ultrasonic transfer function caused by a local temperature rise, wire movement, and epoxy crack etc.. Some experiments were carried out with a small epoxy impregnated superconducting magnet. This time, we have investigated the change of AE sensor's sensitivity. Besides, we have made sensors which don't deteriorate through repetitive thermal-shock tests between room temperature and 4.2K. We can expect more reliable results to diagnose superconducting magnets with this cryogenic-type AE sensors. The experimental results using this sensors show that local temperature rise about 2-3K can be detected before quench. Meanwhile, a quantitative expression of this method has been realized.

****Supported by Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture of Japan.

JC-27 DETECTION AND EVALUATION OF INSTABILITY IN RACE-TRACK SHAPED SUPERCONDUCTING COILS, S. K. Seo, Nishijima, K. Takahata, T. Okada, ISIR Osaka University, Ibaraki, Osaka, Japan

The instabilities in race-track shaped superconducting coils have been evaluated by means of acoustic emission (AE) method in order to establish the methodology of constructing the stable magnets. Small race-track shaped coils were constructed and the training behavior were examined. The mechanical compression and/or epoxy-impregnation were employed for these coils as stabilization methods. The effects of the stabilization methods were also evaluated by AE measurement. The effects on the deformation behavior of the coils were also measured and were compared with the stress distribution and deformation calculated by finite element method (FEM). Good agreement between the experimental results and FEM calculation was confirmed. It is concluded that the AE method was successfully applied as the detection technique of instabilities in superconducting coils and supplied the informations to improve the stability of the coil.

*This work is partly supported by Grant in Aid for Scientific Research No. 63050033, Ministry of Education in Japan.

JC-28 DESIGN AND CONSTRUCTION OF A SUPERCONDUCTING VERTICAL WIGGLER, K, Ohmi, and T. Yamakawa, National Laboratory for High Energy Physics, Oho, Tsukuba, Ibaraki, 305, Japan

A superconducting vertical wiggler which will be installed in the 2.5 GeV positron storage ring as a synchrotron radiation source has been constructed at KEK. The wiggler consists of 5 pair of superconducting magnets with iron pole and will be operated in the permanent current mode using superconducting switched with the field strength of 5 Tesla. Its cryogenic system having a small reliquefier allows the low helium consumption for easier operation. We will present the design and performance of the wiggler.

AUG. 28 (Mon) Session JD (oral) 14:00-15:40

HYBRID MAGNETS-1
Room A

Chairman: K. van Hulst
Univ. of Nijmegen

Cochairman: M. Nishi
JAERI

14:00 JD-01 45 T, STEADY STATE, J. Williams, R. Clarke, Y. Iwasa, M. Leupold, R. Weggel, Francis Bitter National Magnet Laboratory, MIT, Cambridge, MA, USA

As part of a competitive proposal to the National Science Foundation for a new 20 MW U.S. Magnet Laboratory, the Francis Bitter National Magnet Laboratory of MIT is proposing the construction of a 45 T hybrid magnet. A superconducting background field of 15 T will be provided by a duplex magnet; niobium-titanium and niobium-tin sections operating at 1.8 K in subcooled, superfluid helium. It will have a room temperature bore of 455 mm. The windings will be quasi-adiabatically stable with effective heat fluxes of over 2 W cm-2. Our present hybrid magnet inserts operate virtually at the limit of power density in terms of cooling and allowable stresses. In order to utilize all of the increased power, it is necessary to go to a larger diameter. The new insert will use the monohelix construction. Like the polyhelix design, the monohelix is continuous and has no stress concentrations at plate joints. It has the advantage that it allows the use of radial cooling which postpones the thermal limit on current density. The cryostat will have to withstand fault loads, estimated to be as high as 30 tons, arising between the superconducting magnet and the insert. A novel method of constraint of such forces was introduced in the 35 T hybrid system. Large diameter support tubes, concentric with the outer shell of the cold mass provide both axial and radial support. Conceptual design has started. Construction is expected to be complete by 1993.

14:20 JD-02 A DESIGN OF 50 T HYBRID MAGNET FOR QUASI-STATIONARY OPERATION, Y. Nakagawa, G. Kido, S. Miura, A. Hoshi, K. Watanabe and Y. Muto, Institute for Materials Research, Tohoku University, Sendai, Japan

Since 1986, Tohoku hybrid magnet has been producing the field of 31 T, where the superconducting and the water-cooled coils generate 12 T and 19 T, respectively; the electric power consumed by the latter amounts to 7 MW. Recent development of the superconducting magnet may enable us to attain the 40 T field when it is combined with the water-cooled coil consuming more than 15 MW. It seems, however, that the 50 T field is difficult to be produced stationarily, because of the enormous electric power required. Much higher fields have been produced by pulsed magnets with a millisecond duration, and also some quasi-stationary magnets are proposed which produce the fields up to 100 T during several seconds. These magnets are composed of resistive coils only. Now we have designed a 50 T hybrid magnet consisting of 10 T superconducting coil and 40 T resistive coil energized by a quasi-stationary power source. The superconducting coil should withstand the induced voltage due to the rapid change of the field produced by the resistive coil. The resistive coil should be cooled by flowing water or liquid nitrogen quasi-stationarily. The power source of about 30 MW for several seconds consists of a large energy storage such as a fly wheel, a chemical condenser bank and a large superconducting coil. The superconducting energy storage is the most attractive, although it is thought to be the most expensive at present.

14:40 JD-03 THE CONSTRUCTION OF PULSED FIELD SOLENOIDS IN THE OXFORD - LEUVEN COLLABORATION, H. Jones, Clarendon Laboratory, Oxford UK and F. Herlach, Katholieke Universiteit Leuven, Belgium.

At MT10 we reported our success in exceeding the 50 T barrier using a simple conductor / coil configuration (1). In this paper we report the progress of the collaboration over the last two years. During this time we have explored the use of alternative conductors and coil construction techniques. Some interesting problems have come to light particularly with regard to conductor insulation and the use of various coil impregnants. We discuss these aspects illustrating the discussion with our most recent results. As this programme has been the precursor to a much larger European collaboration, which is about to start, and the installation of a new pulsed field facility at the Clarendon Laboratory, we will also discuss its relevance to these initiatives.

Reference

(1) H. Jones, F. Herlach, J.A. Lee, H.M. Whitworth, A.G. Day, D.J. Jeffrey, D. Dew-Hughes and G. Sherratt.
PROC MT10, IEEE Trans Mag 24 (1988) p 1055

15:00 JD-04 GENERATION OF LONG FLAT TOP PULSE FIELDS FOR SOLID STATE PHYSICS, N. Miura, S. Takeyama and K. Watanabe, Insti-tute for Solid State Physics, University of Tokyo, Roppongi, Tokyo, Japan

Pulsed high magnetic fields up to 45 T are produced with a long flat top part by using a pulse-forming-network (PFN)-type condenser bank. The PFN consists of four blocks of condensers and inductances. The total storing energy of the condenser bank is 112 kJ when charged to 4 kV. When necessary, the condenser bank can be also employed to produce an ordinary sinusoidal pulse field by short curcuiting the inductances of the PFN. The pulse magnet has a bore of 20 mm diameter and is wound with a commercial superconducting wire composed by a bundle of Nb-Ti filaments embedded in Cu matrix. The cross-sectional ratio of Cu and Nb-Ti is 3:1. The magnet is operated in a normal state at 77 K, but the Nb-Ti filaments contribute to the mechanical strength of the wire providing the over-all yield strength of about 70 kg/mm^2. The coil is impregnated with epoxy resin at high pressure. Owing to the high strength of the wire, high fields up to 45 T can be produced many times without much deformation of the coil. When the coil inductance is 100 μH, the field pulse has a nearly trapezoidal form with the total pulse width of 4.6 ms, and the field variation during the top flat part is less than 1.5% for 1.2 ms. Such a pulse form is very useful for the application in various solid state experiments when we need a constant field for some long time at the maximum field. The fields were successfully applied to magneto-optical measure-ments by opening a gate of an optical multi-channel analyzer. The flat top pulse field is also useful for transport measurements where the voltage on the sample can be swept at the constant maximum field.

15:20 JD-05 PRIMARY DESIGN OF 40 TESLA CLASS HYBRID MAGNET SYSTEM, K. Inoue, T. Takeuchi, T. Kiyoshi, K. Itoh, H. Wada, H. Maeda, K. Nii, T. Fujioka*, Y. Sumiyoshi*, S. Hanai*, T. Hamajima* and H. Maeda*, National Research Institute for Metals, Ibaraki, Japan, *Toshiba Co., Japan.

The construction of a hybrid magnet system generating magnetic fields of about 40 T at NRIM is one of the major subjects in the Multi-Core Research Project on Superconductivity promoted by the Science and Technology Agency, Government of Japan. At the 1st stage we carried out a R & D study on the candidate materials for magnet conductors, and obtained high J_c Nb_3Sn superconductors (500 A/mm^2 at 16 T and 4.2 K, 1 mm x 1 mm monolith) for the superconducting magnet and high strength/high conductivity Cu-Al_2O_3 and Cu-Nb alloys for the water-cooled magnet. Based on the R & D study, the primary design of a 40 T class hybrid magnet with relevant facilities were worked out. The design assumes generation of a back-up field of 15 T (B_{max} of 15.7 T) at 4.2 K with a superconducting magnet consisting of 50 double pancake windings of 470 mm i.d; each pancake is wound with 4 different cryogenically-stabilized conductors where the grading depends on field distribution. The design also includes use of tape-shape pure Al embedded in the Cu-housing in order to accomplish sufficient stability, especially for the highest-field winding. The water-cooled magnet is designed as a poli-helix type composed of 15 layers to generate incremental fields up to 25 T at about 14 MW power consumption. In the case of power breakdown, an energy of about 5 MJ stored in the chemical condenser is instantaneously released into the magnet to retard its discharge; this method should effectively suppress the damage to the water-cooled magnet and the quench of the superconducting magnet. The construction program will proceed on the base of a 4-year plan starting from 1989 fiscal year.

AUG. 28 (Mon) Session JE (oral) 14:00-15:40

POWER APPLICATIONS-2
Room B
Chairman: A. Fevrier
Lab. Marcoussis
Cochairman: J. Yamamoto
NIFR

14:00 JE-01 TEST OF SUPERCONDUCTING AC FAULT CURRENT LIMITER, D.Ito, E.Shimizu, T.Fujioka and K.Tsurunaga, Toshiba Corporation, Kawasaki, Japan

Fault current limiter is one of the most attractive field for application of superconductivity. We have developed and tested several AC fault current limiters wound with A.C. superconducting cable having ultra fine NbTi filaments. One of the limiters consist of a superconducting limiting coil, i.e. superconducting reactor, and a superconducting trigger coil wound non inductively. Both coils are connected in parallel to each other and in superconducting state in normal operation conditions. The trigger coil has no impedance, therefore, the limiter has no impedance. On the other hand, in the case of fault conditions, the trigger coil quenches at a certain current value. After the trigger coil quenching, the limiter becomes inductive because of current in the trigger coil decreases very rapidly with developing resistive normal zone. Therefore, the fault current is limited by the limiting coil in superconducting state to a certain value determined by the coil inductance. In experiment, we have succeeded to limit the fault current level to 200A with the limiter whose terminalvoltage at the limiting condition was 100V.

14:20 JE-02 **DESIGN AND CONSTRUCTION OF A 50 kA SUPERCONDUCTING TRANSFORMER**
G. Pasztor, E. Aebli, B. Jakob, P. Ming, P. Weymuth
Paul-Scherrer-Institute, 5232 Villigen, Switzerland

In order to enable tests on future full size NET conductors a superconducting transformer was designed and constructed at PSI. The transformer unit which will be used in the SULTAN Test Facility is specified for currents up to 50 kA. The main advantage of such a device where high currents are induced in a superconductor test loop is that large and power consuming current leads are eliminated.

In this paper the design and construction of the transformer components and cryostat are described in detail. Information concerning future operation of this device in the SULTAN-III Test Facility is also given.

14:40 JE-03 INDUCTIVE METHOD FOR MAXIMUM CURRENT TESTING OF SUPERCONDUCTING CABLES, G.B.J. Mulder, H.H.J. ten Kate, H.J.G. Krooshoop and L.J.M. van de Klundert, Applied Superconductivity Centre, University of Twente, Enschede, The Netherlands.

When designing a facility for testing superconducting cables a decision should be made on how the cable is supplied with the required test current. A straightforward possibility is to connect a high-current power supply directly to the sample under test by means of current feedthroughs into the cryostat. The alternative is to generate the current through the sample inductively. In that case, the sample is connected to the secondary windings of a superconducting transformer having a sufficiently high current amplification. The main advantage of the latter method is that very high currents can be generated with relatively low costs. At the University of Twente, this principle of measurement is applied successfully in several test facilities for current levels up to 100 kA.

This paper discusses the advantages and disadvantages of the method of inductive cable testing. Attention will be given to design considerations of the test facility, such as the design of the transformer, the design of the superconducting switch in the secondary circuit, the methods to measure a current in a closed superconducting circuit and the fabrication of joints with sufficiently low electrical resistance.

*These investigations in the program of the Foundation for Fundamental Research on Matter (FOM) have been supported in part by the Netherlands Technology Foundation (STW).

AC LOSS CHARACTERISTICS OF SUPERCONDUCTING POWER TRANSMISSION CABLE

15:00 JE-04 Kazuaki ARAI, Naotake NATORI and Noboru HIGUCHI

Electrotechnical Laboratory
1-1-4 Umezono, Tsukuba-shi, Ibaraki 305, JAPAN

In the near future, it is expected that 1 to 3 GW class power transmission cables would be required, especially in big cities. The superconducting cables are the most appropriate for such power transmission.

Several types of superconducting power transmission cables have been proposed up to the present. The superconducting power transmission cables recently developed in the ETL are designed appropriate for 1 to 3 GW class which are assembled with Nb_3Sn tapes helically wound. They have the length of 10m and outer diameters of 5cm.

Countermeasure against thermal contraction is one of the major factors in the design of this type of cables, especially when superconducting materials applied are brittle. We have assembled the cables under the condition that lay angles of the insulation tapes are varied in order to reduce the affection by thermal contraction.

In this paper, measured ac loss of the cable is also presented.

15:20 JE-05 OFF-ON CHARACTERISTICS OF MAGNETICALLY CONTROLLED SUPERCONDUCTING SWITCH, T. Nitta*, M. Tada*, T. Okada* and S. Isojima**, *Department of Elect. Eng., Kyoto University, kyoto, 606, Japan and **Sumitomo Electric Industries, Ltd., Osaka, 554, Japan.

An experimental magnetically controlled superconducting switch, which is composed of superconducting gate wire (NbZr/CuNi) and superconducting field coil (NbTi/CuNi), has been made. Some experiments for the switching characteristics of the switch have been carried out. The experimental results show special characteristics of switching: 1)At failure of switching-on, the gate current is independent of the initial current and constant and 2)The gate current at the off-on transient state, that is, from the normal state to the superconducting state of the superconducting gate wire, does not depend on the voltage across the gate wire, but depends uniquely on the magnetic field around the gate wire. The gate current can be explained to be a minimum normal-zone propagation current given by the equal-area theorem on cryogenic stabilization. This paper descibes structure of the experimental switch, the experimental results and theoretical approach for the off-on characteristics of the switch.

AUG. 28 (Mon) Session JF (poster) 14:00-16:00

I ACCELERATER MAGNETS
II MAGNET TECHNOLOGY FOR RESEARCHES-1
Room P1 and P2

Chairman: C. Taylor
LBL

Cochairman: S. Mitsunobu
KEK

JF-01 STRUCTURAL ANALYSIS OF THE LHC 10 T TWIN APERTURE DIPOLE. D. Leroy, R. Perin, D. Perini, A. Yamamoto(*), CERN, European Organization for Nuclear Research, Geneva, Switzerland
* on leave from KEK, Oho, Tsukuba, Ibaraki, 305, Japan.

The Large Hadron Collider (LHC) is proposed at CERN as the next facilities to push further the frontier of high energy physics. The design of the superconducting dipole magnets is based upon the "two in one" concept in which the dipoles of the two rings of the collider have a common magnetic ciruit. Twin aperture models (MTA1) designed for a 10 T field level are being developped in collaboration with European Industries. These high field magnets require a sophisticated mechanical design of the various parts as collars, splitted iron yoke and outer shrinking cylinder. A structural analysis of the MTA1 magnets has been made at CERN by using the FEM code "ANSYS". We report on the mechanical analysis and optimization of the magnet during assembly, cooldown and under the electromagnetic foces.

JF-02 DESIGN AND CONSTRUCTION OF A TWIN APERTURE PROTOTYPE MAGNET FOR THE CERN LHC PROJECT, Ph. Lebrun, D. Leroy, R. Perin and J. Vlogaert, European Organization for Nuclear Research (CERN), Geneva, Switzerland.

A twin aperture, 10 m long, prototype magnet was designed by CERN and built by industry in order to gain experience in the construction of full-scale, twin aperture, high-field magnets and in the operation with superfluid helium of such magnets.
In order to gain time and to reduce the cost of development and tooling, use is made of superconducting excitation coils of the same type and geometry as for the dipoles of the HERA proton ring but operated at 1.8°K.
The active part of the magnet consists of two dipole coils wound from a keystoned NbTi cable, clamped with aluminium collars. The collar/coil assembly is surrounded by a split, low carbon steel, yoke enclosed by an aluminium alloy shrinking cylinder.
The cryostat consists of a stainless steel liquid helium container, a radiation screen at 4.5°K, a liquid nitrogen screen and a steel vacuum vessel.
It is expected to reach a 7.5 tesla central bore field at 1.8°K.

JF-03 CALCULATIONS AND MEASUREMENTS OF STRAND COUPLING LOSSES IN A SUPERCONDUCTING MODEL MAGNET FOR THE L.H.C., P. Tixador, D. Leroy, L. Oberli, European Organization for Nuclear Research, Geneve, Switzerland.

In the framework of a future Large Hadron Collider (L.H.C.) at C.E.R.N. high field (8-10 T) magnet models are in development. We have studied and measured the strand coupling losses in a single aperture, 1 meter long dipole. This dipole works at superfluid Helium temperature with a NbTi soldered cable. The calculations are based on the intrinsic decay time constant of the induced currents. This parameter has been obtained experimentaly on a stack of magnet cables. The shape factor has been calculated for any dipole. Modelling the magnet as a transformer with a lossless primary and a secondary short circuited on a resistance representing the induced currents losses we have shown that the losses during a discharge may be calculated only from the simple measurement of the tension of the dipole after the current of the magnet becomes zero. Calculations and measurements are performed for discharges of magnet at high current rates (80 - 200 A/s). The results from calculations and measurements are in good agreement .

JF-04 INDUSTRIAL FABRICATION OF A 10 TESLA TWIN APERTURE DIPOLE MODEL FOR LHC AT HOLEC, F. van Overbeeke, R.L. Dubbeldam, Holec, Ridderk, the Netherlands, and H.H.J. ten Kate, University of Twente, Enschede, The Netherlands.

In the course of the main dipole development for LHC, CERN has commissioned a number of model magnets for industrial fabrication. These prototype magnets differ from the final magnets mainly in the fact that they have an axial length of 1 m instead of 10 m.

The models to be built now are based on a general design by CERN (1). However, especially in the field of construction engineering, a considerable amount of preparatory work still had to be done by the manufacturing industries.

One of the models is being fabricated at the works of Holec in Ridderkerk, the Netherlands, and is planned to be ready in the fall of 1989. The engineering and production are closely related to the development program of the Dutch 10 tesla Nb3Sn LHC model magnet (2,3). The paper presents the engineering and manufacturing process and the current status of manufacture.

(1) D. Leroy, R. Perin, G. de Rijk, W. Thomi, Design of a high-field twin aperture superconducting dipole model, Proc. MT-10, Boston, September 23, 1987.

(2) H.H.J. ten Kate et al., On the development of a 1 meter 'twin aperture' 10T Nb3Sn dipole magnet for the CERN LHC, SSC Conference, New Orleans, february 1989.

(3) H.H.J. ten Kate et al., presented at this conference.

JF-05 FABRICATION AND TESTING OF A NIOBIUM-TIN CABLE DESIGNED FOR THE OUTER COIL OF AN LHC DIPOLE, by E.M. Hornsveld[1], W.M.P. Franken[1], J.A. Roeterdink[1], J.A. Eikelboom[1], S. Wessel[2], B. ten Haken[2], H.H.J. ten Kate[2]. 1: ECN Netherlands Energy Research Foundation, The Netherlands, 2: University of Twente, Enschede, The Netherlands. In the scope of the development of the LHC-dipole conductors a keystone-shaped Rutherford cable has been fabricated. The cable consists of 36 strands of niobium-tin wire with a diameter of 0.90 mm and 192 filaments. The wire was produced following the ECN powder method which is based on hollow niobium filaments with a core of $NbSn_2$ powder. The filaments are embedded in a matrix of OFHC copper. The superconducting Nb_3Sn layer inside the niobium filaments is formed by a heat treatment at 675°C during 64 hours. A sample of the cable has been tested in the ECN 13 tesla test facility using a flux transformer, designed by the University of Twente. At 13 tesla a critical current of 11.8 kA has been measured and at 8.5 tesla a critical current of 30.8 kA has been measured, which is about 65 % higher than the specified value for the cable material of the outer LHC coil.

JF-06 DEVELOPMENT OF SUPERCONDUCTING DIPOLE MAGNETS FOR ACCELERATOR, T. Shintomi, National Laboratory for High Energy Physics, K. Asano and T. Yamagiwa, Hitachi, Ltd., Japan

Small bore and high field dipole magnets are required for high energy hardron colliders to minimize cost of the facilities. In accordance with this requirements three 1.4 m - long dipoles with a 40 mm coil inner diameter and a field of 6.6T have been built and tested. The main features of the dipoles are a two layer cos θ superconducting coil, made from NbTi Rutherford type cables, clamped with 1.5 mm thick high manganese steel laminations and a cold laminated iron yoke surrounding the collared coil. The copper to superconductor ratio of inner coil cable, yoke structure and manufacturing method of the coil etc. are intentionally changed in the three magnets to compare the magnet performance.

JF-07 THREE DIMENSIONAL MAGNETIC FIELD ANALYSIS FOR 5 m SUPERCONDUCTING DIPOLE MAGNET, H. Hirabayashi, T. Shintomi (KEK National Laboratory for High Energy Physics), K. Kondo, M. Yamaguchi, S. Itoh, S. Murai, M. Wada (Toshiba Corporation)

It is customary that the superconducting dipole magnets for the particle accelerators are surrounded with the return iron yokes in order to achieve field enhancement. The characteristics of the superconducting magnets are governed by the field strength from the point of view of the critical current margin and the superconducting stability. Therefore, precise field analysis is required for the superconducting magnets with the return iron yokes, in particular dipole magnets whose shape is not axisymmetric and which exhibit complicated electromagnetic performances, especially at the coil end regions. Saddle shaped coil end regions need to be tightly supported against the electromagnetic force and also thermal contraction in order to avoid conductor movements, however, it is not so easy to solve it, considering that configuration. Accordingly, it is a pertinent way to lower the magnetic field at this region. For this purpose, the return iron yoke is voided annularly at the portion of coil ends. The three dimensional magnetic field analysis is performed for 5 m superconducting dipole magnet to evaluate the above effect. The magnetic field is analyzed with the three dimensional nonlinear magnetic field analysis program by integral equation method, and mesh generation programs for both the iron yokes and the saddle shaped coils. As a result of field analysis, it is made clear that the adoption of annular void is effective, reducing the peak field at the end regions. The validity of the above analysis is confirmed in comparison with the results by three dimensional coreless field analysis and two dimensional nonlinear field analysis.

JF-08 DESIGN AND SERIES MANUFACTURE OF COILS WOUND WITH ANODIZED ALUMINIUM STRIP FOR THE LEP QUADRUPOLES, P. Bogliolo*, G. Dal Mut* and C. Wyss, CERN, Geneva, Switzerland, and *ANSALDO COMPONENTI, Genoa, Italy

Excitation coils wound with anodized aluminium strips, cooled by heat conduction to water-cooled heat sinks, have been developed and successfully produced in a large series to equip 290 quadrupole magnets for the LEP storage ring. The choice of the design parameters, the achieved electrical and thermal performance and the experience gained with the series production of this type of coil, particularly suited for the design of low-current, high-impedance coils, are reported.

JF-09 ANALYSIS OF THE PERFORMANCE OF THE EIGHT SUPERCONDUCTING QUADRUPOLES FOR THE LEP LOW-BETA INSERTIONS, P.J. Ferry*, Ph. Lebrun, S. Pichler, D. Semal*, T.M. Taylor, T. Tortschanoff, L. Walckiers and L. Williams, CERN, Geneva, Switzerland, and *ALSTHOM, Belfort, France

The LEP low-beta quadrupoles are iron-free superconducting magnets having a warm bore of 120 mm in diameter, an effective length of 2 m and a nominal gradient of 36 T m^{-1}. The coils form a two-block approximation of the cosine 2θ distribution, and are wound from monolithic multifilamentary NbTi conductor; mechanical prestress is obtained by means of aluminium shrinking rings. Following manufacture and appraisal of a prototype magnet, eight series units have been produced by industry and thoroughly tested and measured prior to installation into LEP. In this paper, a brief description of the manufacturing technique is given, and the results of tests and measurements are presented and compared with the performance expected from calculations and previous experience. The analysis reveals the tolerances on field quality which can reasonable be obtained with this type of construction.

JF-10 STATUS OF MAGNET SYSTEM FOR RHIC*, P.A.Thompson, J.Cottingham, R.Fernow, M.Garber, A.Ghosh, C.Goodzeit, A.Greene, R.Gupta, H.Hahn, J.Herrera, S.Kahn, E.Kelly, G.Morgan, S.Plate, A.Prodell, W.Sampson, W.Schneider, R.Shutt, J.Skaritka, P.Wanderer, E.Willen, Brookhaven National Laboratory,Upton NY,11973. The proposed Relativistic Heavy Ion Collider (RHIC) will operate at ion energies of 7 to 100+ GeV/AMu for ions as heavy as Au-197. This paper discusses the status of the superconducting magnet system for this machine. This will consist of:372 dipoles typically 9.7 meters long with an operating field of 3.5 Tesla, 492 quadrupoles with typical length 1.2 meters, gradient 74 T/m, and 810 sextupole and corrector magnets. These will be installed in two intersecting rings 3834 meter in circumference. Seven full size test dipoles and two quadrupole-sextupole units have been constructed and tested. All exceeded the operating current for all quenches. The dipole and quadrupole magnets use a single layer of superconducting cable. This achieves the desired field, while greatly simplifying the construction of the magnets. information gained from these magnets and the ongoing SSC program has been used to refine the design of the magnet system. This paper presents test results and design parameters for this system.

*Work performed under the auspices of the U.S. Department of Energy.

JF-11 THE BENDING MAGNET SYSTEM OF LEP, M. Giesch and J.P. Gourber

The main bending magnets of LEP are made of 3280 "steel-concrete" cores of 5.75 m length, disposed end-to-end in long units of generally six cores. Just prior to transportation in the tunnel, the cores are pre-assembled at the surface in pairs equipped with their four water-cooled aluminium bars and with their vacuum chamber. The bars are welded together in the tunnel by the MIG process so as to form a single powering circuit equivalent to one turn on each pole. Water-cooled cables are used to interconnect the bending magnets between the arcs. The paper recalls the main features of the cores and describes in more detail the excitation circuit; the criteria retained for the design of the bars and cables are presented together with the experience gained with the series production and with the assembly and interconnection of the magnets.

JF-12 MECHANICAL ANALYSIS OF DIFFERENT YOKE CONFIGURATIONS FOR THE SSC DIPOLE, M.S. Chapman, J.M. Cortella, R.I. Schermer (SSC Central Design Group), R.H. Wands (Fermilab). Recent SSC R&D dipole magnets have incorporated the iron yoke and helium containment shell in the mechanical support structure for the coils heretofore consisting of the collars alone. Finite element methods are used to calculate the additional support offered by different configurations of the yoke and shell. In this parametric analysis, horizontally and vertically split yokes are considered, as well as different collar/yoke contact surfaces and different yoke midplane conditions. The mechanical advantages and disadvantages of the different configurations are discussed and related to other magnet design considerations such as ease of construction and perturbation of magnet field harmonics.

JF-13 DIPOLE AND QUADRUPOLE MAGNETS DESIGN WITH 2D AND 3D ELECTROMAGNETIC ANALYSIS CODES

A.Matrone(+), P.Molfino(*), P.Prati(+), M.Repetto(*)
(*)Dip. Ing. Elettrica, 11a V. Opera Pia, I-16145 Genova,Italy
(+)ANSALDO Ricerche, 25 C. Perrone, I-16152 Genova,Italy

The design of dipole and quadrupole magnets has to satisfy rather stringent requirements relevant to field related quantities, like uniformity of flux density in dipole magnets and uniformity of gradient of flux density in quadrupole magnets. In spite of the precision required in the evaluation of the previous quantities, usually in the order of 10-100 p.p.m., accurate estimates of them can be obtained, in the central zone of the device, by means of two dimensional finite element codes. Unfortunately, the estimates so obtained are not sufficient for a complete definition of the magneto-optical properties of the devices; these properties, in fact, depend significantly also on the behaviour of flux density in the end region of the device.

The two main quantities that would require a real three dimensional evaluation of fields are the effective magnetic length, which is tied to the evaluation the behaviour of the integral of flux density along the azimuthal direction on the device axis and the behaviour of the previous integral as function of the transverse coordinate. While in the evaluation of the magnetic length a two dimensional analysis in an azimuthal cross section can be of help, the latter analysis requires a really three dimensional code. In order to realize a first tentative design of the shape of the end part of the device, two dimensional analysis code can be used but have to be verified by means of 3D results. The results obtained by the comparison of two dimensional simplified approach versus three dimensional computation, together with a parametric study of the end part of the devices will be presented in the paper.

JF-14 CRITICAL CURRENT MEASUREMENT OF PROTOTYPE CABLES FOR THE CERN LHC UP TO 50 kA BETWEEN 7 AND 13 TESLA USING A SINGLE STEP SUPERCONDUCTING RECTIFIER*, H.H.J. ten Kate, B. ten Haken, S. Wessel, T. Roeterdink+, E. Hornsveld+, Applied Superconductivity Centre, University of Twente, Enschede and (+) ECN, Petten, The Netherlands.

In the framework of the LHC magnet development programme it is essential to have the opportunity to test the current carrying capacity of the proposed superconducting cables. The operating current of these magnets of about 16 kA at a magnetic field of 10 T makes it expensive to apply a standard V-I measuring procedure using a high-current power supply and a direct feeding of the sample through heavy current leads. In order to overcome these problems and to reduce the costs of such experiments we apply a superconducting power supply i.e. a single step superconducting rectifier to generate the current in the sample. This method of maximum current testing avoids the enormous helium loss due to the 50 kA current leads (for I_c at 7 T) and very costly 50 kA power supply. Instead of this the superconducting supply can be controlled by a common 100A/10V power unit. Especially for the critical current test of several LHC-type superconducting cables with Nb_3Sn strands we designed and built such a device. The sample in the form of a hair-pin or a single layer coil with a few turns is connected to the superconducting supply. The device provides a maximum test current of 50 kA. Several Nb_3Sn cables were investigated in external magnetic fields between 7 and 13 T using the high field magnet facilities in our laboratory and at ECN.

*Supported in part by the Netherlands Technology Foundation STW.

JF-16 SUPERCONDUCTING QUADRUPOLE MAGNETS FOR THE TRISTAN LOW-BETA INSERTION, K. Tsuchiya, N. Ohuchi, A. Terashima, H. Nakayama and K. Egawa; KEK, National Laboratory for High Energy Physics, 1-1 Oho , Tsukuba-shi, Ibaraki-ken, 305, Japan, K. Asano and T. Yamagiwa; Hitachi Ltd., Hitachi-shi, Ibaraki-ken, 317, Japan

This paper describes the construction and test of the first industry-made two superconducting quadrupole magnets which are intended to be used for the TRISTAN low-beta insertions. These magnets are an iron-free type and have dimensions of 140 mm coil inner diameter, 280 mm collar outer diameter and 1450 mm physical length. The design field gradient is 70 T/m and a good field aperture is 80 mm in diameter. The coils which are a cos2θ type are made from four layers of 27-strand NbTi Rutherford cable with Kapton insulation and are clamped firmly with 316LN stainless steel collars. During the first test in a vertical cryostat, these magnets achieved their design currents of 3400 A with only one training and reached 4000 A after 5 quenches. The quench characteristics and field qualities of these magnets were very similar.

JF-17 FILAMENT AND CABLE MAGNETIZATION IN SUPERCONDUCTING ACCELERATOR DIPOLES*, D. ter Avest and L.J.M. van de Klundert, University of Twente, Enschede, The Netherlands

During the ramping of superconducting dipole magnets as used in the SSC or CERN-LHC project, magnetization will manifest itself in the conductor perturbing the field homogeneity of the dipole. A numerical method was developed that covers the calculation of magnetic field inside the conductors, keystoned cables, current redistribution due to the variation of field with time as well as multipole distribution in the dipole. For the calculation of current redistribution in a cable a keystoned geometry is used, although the method applies to any geometry. The model incorporates saturation in the cable. However, in case of an unsaturated cable the current redistribution can be described completely analytically. Also the model allows the calculation of the a.c. loss as a function of the time varying magnetic field. Finally, persistent current effects are described.

The model was converted into a computer code and applied to the design of a CERN-LHC 10T dipole magnet. A relation will be presented that shows the dependence of the change in multipole distribution with the time varying field as well as with a few material properties. Also the effect of persistent currents on the multipole distribution will be shown. This work is part of the UT-NIKHEF programme in The Netherlands to develop a 1 meter Nb_3Sn twin aperture dipole magnet for LHC at CERN Geneva.

*Supported in part by the Netherlands Technology Foundation STW.

JF-18 Corrective Coils for the Electron Cooler at ESR; T. Odenweller, B. Langenbeck; Gesellschaft für Schwerionenforschung Darmstadt (GSI), Planckstraße 1, 6100 - Darmstadt (FRG)

At GSI heavy Ions up to Uranium have been accelerated in the Unilac since 1975. The maximum specific projectile energy of 10 MeV/u was upgraded to 20 MeV/u in 1982. Plans to extend the accelerator facility by the addition of the synchrotron SIS (Schwer-Ionen-Synchrotron) and the storage and cooler ring ESR (Experimentier-Speicher-Ring) were approved in 1985. The Experimental Storage Ring ESR presently under construction at Darmstadt (FRG) is designed for accumulation, storage and cooling of heavy ion beams up to Uranium with Energies up to 500 MeV/u.

A combination of stochastic precooling and electron cooling will be used to reduce the extension of the ion beam in phase space. Electron cooling will take place in a solenoid magnet, where an electron beam of 310 keV and up to 10 A will be directed to circle round the ion beam at a radius of 2.5 cm. A high degree of field homogeneity ($\frac{\Delta B}{B} \leq 10^{-4}$) inside the solenoid magnet has to be established because the quality of electron cooling is closely related to the field homogeneity. Therefore measurements and possibly corrections of the field homogeneity inside the solenoid magnet have to be done. This contribution presents a measurement technique together with data evaluation based on Fourier-analysis and a method to correct for field inhomogeneities by installation of corrective coils.

JF-19 DYNAMIC AND MAGNETIC BEHAVIOUR OF LARGE SUPERCONDUCTING COILS IN THE MAGNET OF THE MILAN HEAVY ION CYCLOTRON, E. Acerbi and L. Rossi.

The magnet of the Milan Superconducting Cyclotron has been successfully excited at the beginning of this year. The maximum average field of 5 Tesla has been reached without troubles (no training and no short circuit). The superconducting coil, 2.4 meter in diameter, wound with a NbTi monolithic cable have been assembled in two sections, indipendently excited, and have been installed in a complex iron circuit. So big forces and moments, strongly depending on the current level, arise by the radial and axial decentering and tilting of the coil and by lack of symmetry in the iron yoke. The paper presents the measurements of these forces and moments, as a function of the currents in the two coil sections, of the magnetic field level, of the coil deplacements and tilting, comparing the results with the theoretical calculations. Finally the effects of the coil decentering and movements on the magnetic field properties are evaluated and compared with the high precision magnetic measurements carried out on the magnet.

JF-20 DESIGN OF AN A.C MAGNETIC BIASING CIRCUIT FOR THE KAON FACTORY BOOSTER R.F. CAVITY, C. Haddock, R.L. Poirier, T. Enegren, M. Zanolli(3), TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3 Canada.

The resonant frequency of an r.f. cavity to be used in the booster ring of the TRIUMF KAON factory, is determined by the state of magnetization of a set of 6 rings of G810 aluminium doped yttrium-iron garnet ferrite. The design of an a.c. magnet which performs the required magnetization is presented. The use of the a.c. magnet code PE2D to study eddy current effects in the walls of the r.f. circuit and the G810 cooling circuit is described.

JF-21 **WITHDRAWN**

JF-22 HIGH CURRENT DENSITY SUPERCONDUCTING MAGNET FOR GYROTRON, V.R.Karasik, V.S.Vysotsky, O.A. Kleshnina, S.G.Deryagin, S.M.Levin, V.A. Malgynov, A.P. Srietsky, P.N.Lebedev Physical Institute, USSR Academy of Sciences, Moscow, F. Chovanec, J.Kokavec, L. Krempasky, P.Usak, B.Gregor, Electrotechnical Institute, Slovak Academy of Sciences, Bratislava, Czechoslovakia.

The detailed stress and strain analysis of the magnet structure (bobbine, winding, bandage) has been used for designing of 7.75 T high current density gyrotron magnet. The numerical computer simulation model enables to calculate the stresses and strains during the magnet winding, cooling and charging processes as a function of the prestressings applied to the superconducting and bandage wires. The appropriate wire prestressing may thus be determined so as to suppresse or eliminate the magnet training and degradation. The multifilamentary NbTi superconducting wire of 1 mm in diameter was used for constructing the magnet. The magnet has inner and outer winding diameters of 192 mm and 320 mm, respectively. The winding was epoxy potted and reinforced by external bandage made of a stainless steel wire. The magnet consists of 6 sections shunted by protection low ohmic resistors and is equipped by the superconducting switch enabling the operation in the persistent mode. At the tests the magnet current reached short sample performance (186 A, maximum winding magnetic field 8.7 T). Overall winding current density reached the value of 1.6×10^8 Am^{-2}, stored energy was 300 kJ. The magnet is a part of a system for 140 GHz gyrotron generator.

JF-23 SUPERCONDUCTING MAGNETIC SYSTEM OF THE SPECTROMETER FOR ELECTRON ANTINEUTRINO MASS MEASUREMENT. A.I.Belesev, A.I.Bleule, E.V.Geraskin, A.A.Golubev, N.A.Golubev, O.V.Kazachenko, Yu.E.Kuznetsov, V.M.Lobashev, B.M.Ovchinnikov, I.V.Sekachev, A.P.Solodukhin, I.E.Yarykin., INR of AS of the USSR, Moscow, USSR.

It is described the design and test outcomes of a superconducting magnetic system of the electro static spectrometer with adiabatic magnetic collimation, intended to measure electron antineutrino mass through tritium decay β-spectrum analysis. The spectrometer magnetic field is shaped in the form of axially symmetric magnetic trap with 2 plugs, the fields them being 8.5Tl and 2.7Tl. The distance between the plug centers is about 6.5 meters. Two-phase helium mixture at 0.5-0.6 atm and 4.6-4.7 K passes all the cryostats. The cooldown solenoids and cryostats mass is 350 Kg, the total heat rating is 30-40 Wt.

JF-24 A NEW SUPERCONDUCTING SOLENOID DEVELOPMENT FROM A MAGNETIC SHIELDING DEVICE MADE OF NbTi-Cu FILMS, S.Ogawa*, K.Nishigaki**, Y.Saji***, T.Sugioka***, M.Inoue***, Osaka Prefectural Industrial Research Institute,Osaka,Japan*, Kobe University of Merchantile Marine,Kobe,Japan**, Koatsu Gas Kogyo Co.,Ltd.,Osaka,Japan***

As an application of superconducting NbTi-Cu multi-layer film, we made a new designed small superconducting solenoid taking advantage of trapping behavior of type II superconductor and studied the magnetizing characteristics: A test cylinder was made by piling superconducting disks and aluminum disks alternately. Both disks were made of a concentric circle with one hole. Size of test cylinder was outside diameter 35mm, inside diameter 10mm, height 20mm and nine pieces of superconducting disks were piled against 1mm of cylinder height. Using this cylinder, we examined magnetic flux density trapped inside cylinder bore when magnetic flux density around test cylinder was varied. It was proved that magnetic flux density trapped inside the cylinder bore was optionally controlled. In addition, when outer magnetic flux density exceeded a maximum magnetic flux density, trapping flux density became constant and showed more than 0.8T in this test cylinder.

As a individual superconducting disks examined had no uniting part, there was no change of persistent currents with time. In other word, no change was seen in magnetic flux density trapped inside the cylinder. Trapping flux density increased as the density of piled up superconducting disks increased, so that it can be possible to trap at a high magnetic field of the order of some teslas.

JF-25 SUPERCONDUCTING MAGNETIC FLUX SHIELD WITH BRONZE PROCESSED Nb3Sn TUBE,*M.Ohgami, K.Takahata, K.Katagiri, S.Nishijima, T.Okada, ISIR Osaka University, Ibaraki, Osaka 567

Magnetic shield made by Nb3Sn tube have been developed in order to shield the high magnetic field. The shielding tubes with the dimension of approximately 50mm in length and 40mm in diameter were made by using a bronze processed Nb3Sn stabilized with copper . The transverse field was applied to the tubes and the field penetration was measured at the center of the shielding tube at 4.2K. The shield can maintain the shielding capability up to several Tesla in the transverse field. The shielding efficiency of Nb3Sn was compared with that of NbTi shield. The stability of Nb3Sn superconducting shield was also discussed from the viewpoint of copper to super ratio of the shields and compared with that of NbTi multifilamentary shield.

*Resarch partly sponsored by Grant in Aid for Scientific Research No.6350033, Ministry of Education in Japan.

JF-26 A HIGH CURRENT DENSITY SUPERCONDUCTING SOLENOID WITH JOINTS WITHIN THE WINDING, Yan Luguang, Qin Jie, Yi Changlian, Wang Shiliang, Xu Deji*), Xu Renxiang*), Institute of Electrical Engineering, Academia Sinica, Beijing, China

To test the feasibility of making conductor joints within the winding, a 80 mm inner diameter solenoid has been designed and constructed. Eight short rectangular, varnish-coated conductors are used. Suitable diffusion welding joint technique has been developed, the joint resistance obtained is in the range of 10^{-11} to 10^{-13} ohms at 4.2K and zero field, its strength is higher than 80% of the conductor strength. The solenoid is layerly wound, between layers are 0.45 mm wide narrow helium channels for conductor cooling. The magnet test shows that the magnet achieved the "short-sample" performance without training and can withstand as high as 1.68T/s charging rate without degradation. The corresponding central field is 7.12 T, peak field is 7.64 T, stored energy is 36.7 KJ, NbTi current density is 725 A/mm^2, conductor current density is 207 A/mm^2 and overall winding current density is 149 A/mm^2, i.e. on the same level of the typical close-packed, high current density magnets. This design priciple and joint technique will be used for the design and construction of a 0.6 m inner diameter and 5 T solenoid for high gradient magnetic separator.

*) From Northern Jiaotung University.

JF-27 NEW ANALYTIC FORMULAS FOR CALCULATING MAGNETIC FIELDS, FLUXES, AND VECTOR POTENTIALS, C. Weggel, MatheMagic, San Diego, California, U. S. A.

Extremely fast and accurate analytic formulas have been derived for calculating the magnetic field and vector potential generated by any system of uniform-current-density polyhedral elements. These formulas are derived by three-fold analytic integration of $\boldsymbol{J}\times\boldsymbol{r}\,dV/r^3$ or $\boldsymbol{J}\,dV/r$ throughout the volume of the windings. Based on these new formulas, several computer programs have been written to design, analyze, and optimize not only axisymmetric, but also non-axisymmetric, three-dimensional systems. These computer programs are several hundred times faster and more accurate than their best predecessors, typically yielding an accuracy of better than one part per million, regardless of the magnet geometry. These programs have been used to analyze numerous magnet systems, including the Ohmic Heating (OH) and Equilibrium Field (EF) systems for the Confinement Physics Research Facility (CPRF) at the Los Alamos National Laboratory (LANL), the ion-diode coils of the Particle Beam Fusion Accelerator (PBFA-II) for Sandia National Laboratories (SNL), and the OH and EF systems for the TITAN Reversed-Field-Pinch (RFP) commercial fusion reactor study for UCLA.

JF-28 POLE SHAPING FOR IMPROVING THE DEVIATION OF THE EFFECTIVE LENGTH IN THIN QUADRUPOLE MAGNETS S. Yamamoto, M. Morita, T. Matsuda and T. Yamada Mitsubishi Electric Corp.,Amagasaki,Hyogo,661 Japan

Shapings of pole ends for improving the deviation of the effective length of the magnetic field gradient, $(\lg(X)-\lg(0))/\lg(0)$, in thin quadrupole magnets had been studied experimentally and analytically. Two types of conventional quadrupole magnets, with a sharp cut-off or no cut-off of pole ends, had been made respectively. The bore diameter/core length ratio of the magnets is 0.068m/0.05m = 1.36. The rated field gradient is 3.5T/m. In the fabrication of the magnet, the end cut shape was approximated by three steps. Magnetic fields were measured by moving coils (short coil, 0.0085m in length and long coil, 0.352m) and a thermally controlled Hall-probe. The deviation of the effective length with sharp cut-off of the pole ends was $2\times10^{-3}/|X|\leq0.02$m. The deviation with no end cut was $1.6\times10^{-2}/|X|\leq0.02$m which was 8 times larger than that with end cut. The measured effective length of field gradient was 0.079m which was 1.6 times longer than the core length. Three dimensional magnetic field analyses were also performed. The experimental results were in agreement with the analyses.

JF-29 Three Dimensional Analysis of the Deflection Yoke with Surface Charge Method. T. Nakagawa, S. Okuda, M. Ogasa, H. Nishino, Mitsubishi Electric Corporation, 1-1, Tsukaguchihonmachi, 8 Chome, Amagasaki, 661, JAPAN

Since a deflection yoke (DY) mounted on a cathode ray tube (CRT) has been designed by experiences, it took much time and cost to develop a new deflection yoke. The computer simulation is required to reduce time and cost. Since the core of a conventional DY is rotationally symmetric, its magnetic field can be calculated by a two dimensional model. A large deflection angle of large screen CRTs leads to using a core with rotationally asymmetrical slots. A three dimensional field analysis is necessary to simulate the performance of this DY. Among various three dimensional analyses, surface charge method was selected because the data is easily input and it can analyze the wide regions. The developed program was verified with a simple model and the efficiency and convergence quality were compared with the measurements.

JF-30 3-D MODEL OF A TOROIDAL MAGNET FOR THE CALCULATION OF CURRENT AND TEMPERATURE DISTRIBUTIONS UNDER FAULT CONDITIONS: THEORETICAL ASPECTS, I. Montanari, P.L. Ribani, Facoltà di Ingegneria, Università di Bologna, Italy.

The evaluation of the internal and external stresses acting on the coils is affected by the precision to which the electrical parameters are known. The previous studies demonstrate that the short of a coil is very severe for the forces status and a well estimate of the current and temperature distribution inside the coils becomes more important. The described model is obtained by means of the field theory using the differential approach and considering the power supply, and it allows to calculate the distribution of the current and the temperature inside the turns of the windings. The coils are not studied as monolithic but with their own turns with trapezoidal cross section. The region to be meshed includes the faulted coil and two coils on both sides of it. This reduction of the region is justified by the circuit model which demonstrates that the fault effects is rapidly reduced leaving the faulted coil. As a consequence the dimension of the problem becomes acceptable for computing.

AUG. 28 (Mon) Session JG (oral) 16:00-17:40

HADRON COLLIDER TEST MAGNETS-2
Room A

Chairman: R. V. Perin
CERN

Cochairman: A. Yamamoto
KEK

16:00 JG-01 DEVELOPMENT OF A 10 T Nb_3Sn "TWIN APERTURE" MODEL DIPOLE MAGNET FOR THE CERN LHC, H.H.J. ten Kate, C. Daum,* L.J.M. van de Klundert, W. Hoogland,* T.A. Roeterdink,# F. van Overbeeke,& R. Perin.° University of Twente, Applied Superconductivity Centre, Enschede, (+) NIKHEF-H, Amsterdam; (#) ECN, Petten; (&) HOLEC, Ridderkerk; all in the Netherlands; and (o) CERN, Geneva, Switzerland.

The possible realization of the new 8 TeV hadron collider LHC of CERN presupposes the availability of the techniques to construct 10 tesla twin aperture dipole magnets either by using conventional NbTi technology at 1.8 K or by using a Nb_3Sn conductor at 4.2 K. At present both alternatives are under development at CERN in collaboration with European laboratories and industries. A new initiative to explore the Nb_3Sn route was started in 1988 by a team in the Netherlands in which the Applied Superconductivity Centre at the University of Twente and NIKHEF, the National Institute for Nuclear and High Energy Physics and STW participate. In cooperation with CERN a 4 years R&D program was started to design and to manufacture a 1 meter Nb_3Sn dipole model coil in collaboration with other research institutes and companies in the Netherlands. The magnet now under development will be the first Nb_3Sn twin aperture LHC dipole magnet designed for use at a nominal field of 10 T. The paper reports on general aspects of the development programme for the magnet, the main design considerations and the present state of the developments.

• Supported in part by the Netherlands Technology Foundation STW.

16:20 JG-02 TEST RESULTS FROM 1 M MODEL SSC DIPOLE MAGNETS* J. Strait, R. Bossert, J. Carson, M. J. Lamm, and P. Mantsch, Fermi National Accelerator Laboratory, Batavia, IL 60510 -- Results are presented from tests of 1 m model magnets for the Superconducting Super Collider. These magnets have been made in preparation for the construction of full length magnets at the Fermilab SSC Pilot Production Facility. They have the same design as the long magnets (except for coil length) and are made on tooling of the same design used to produce the full scale models. In addition to certifying the tooling and assembly techniques, these magnets test a number of design features. By careful design of the yoke-collar interface and by pre-tensioning the outer cold-mass skin, additional mechanical support is provided to the collared coil to minimize deflections under excitation. A new constant perimeter end design and a new inner-outer coil splice have been incorporated. These magnets are extensively instrumented with voltage taps to locate the origin of quenches and with strain gages to measure stresses and deflections during manufacture, cooldown and excitation. Measurements of mechanical properties, quench performance and magnetic field quality will be presented.

*Operated by the Universities Research Association under contract with the U. S. Department of Energy.

16:40 JG-03 DEVELOPMENT OF SUPERCONDUCTING DIPOLE WITH IDEAL ARCH STRUCTURE USING LARGE KEYSTONE ANGLE CABLE, T. Shintomi, A. Terashima and H. Hirabayashi, National Laboratory for High Energy Physics, H. Miyazawa, Hitachi Ltd., T. Kawaguchi, Mitsubishi Electric Corp., S. Murai, Toshiba Corp., Japan -- High energy hadron colliders require a large number of superconducting magnets, and then the simple fabrication processes and the high yield rate are very important. However, the aperture of those accelerator dipole magnets is relatively small, for example 40 mm in diameter for SSC and 50 mm for LHC. There are some problems for such small aperture dipole magnets. Those are difficulty of the fabrication at the end section with a small bending radius, necessity of keys between windings to cancel the difference of the arch of the coil cross section from keystone angle of the cables, inevitable diminution of the average current density of the windings, complex fabrication processes caused by keys, and so on. To avoid the above disadvantages, we have developed cables with a large keystone angle of 3 degrees and designed a dipole magnet with an improved cross section. The large keystone angle cable can be fitted to the dipole of the ideal arch structure which has a coil inner diameter of 50 mm without any keys inside. The cable has been tested for the degradation with several values of the compaction factor. We obtained good properties of the critical current density with small degradation. The coil has very simple cross section and high overall current density. The winding processes may be expected to be simple because the dipole has no wedges between windings. This will be very effective to obtain good performances and high yield rate.

17:00 JG-04 TRAINING IN HIGH-PERFORMANCE SUPERCONDUCTING DIPOLE MAGNETS AND ROOM-TEMPERATURE ACOUSTIC SIGNAL ATTENUATION* O. O. Ige† and Y. Iwasa†
MIT Plasma Fusion Center, Cambridge, MA, USA

High-current-density superconducting dipole magnets such as those used in accelerators are susceptible to premature quenches due to mechanical disturbances, chiefly conductor motion and epoxy cracking. If indeed mechanical disturbances are the major cause of quenches, then the firmness of clamping of the coils will affect the 4.2-K performance of the magnets. We believe that the attenuation of suitable acoustic signals through the magnet structure provides a measure of the tightness of clamping of the coils in the magnet. Such attenuation data taken from 1-m dipoles are shown to correlate well with their training rates. Attenuation data obtained thus far from superconducting supercollider (SSC) dipoles are very close in magnitudes; so are their training rates. A simple theoretical explanation of these observations, based on the concept of *local effective coil stiffness*, is presented. The spectral contents of acoustic emission (AE) signals at various positions along the SSC magnets is linked with the local effective stiffness of the coils in those locations.

* Supported by the Division of High Energy Physics of the U.S. Department of Energy.

† Also the Department of Mechanical Engineering, MIT.

17:20 JG-05 TIME DEPENDENCE OF EDDY CURRENT EFFECTS IN THE SUPERCONDUCTING HERA MAGNETS, H. Barton, H. Brück, D. Gall, G. Knies, R. Meinke, H. Preißner, P. Schmüser, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

For the superconducting magnets of the HERA accelerator, presently under construction at the DESY laboratory in Hamburg, the time dependence of persistent eddy currents in dipoles and quadrupoles have been measured. The main fields and different higher-order multipole fields show a logarithmic dependence on time over a wide range from a few minutes to several hours. Correlations of this effect with parameters of the superconducting cables as well as operating conditions of the magnets will be presented.

AUG. 28 (Mon) Session JH (oral) 16:00-17:40

HIGH Tc SUPERCONDUCTORS-2
Room B

Chairman: M. A. Hilal
Univ. of Wisconsin

Cochairman: T. Ohnishi
ETL

16:00 JH-01 THE CRITICAL CURRENT TESTING OF HIGH T_c SUPERCONDUCTORS IN HIGH MAGNETIC FIELDS, L. Cowey and H. Jones, Clarendon Laboratory, Oxford and D. Dew-Hughes, Dept. of Engineering Science, Oxford.

The Clarendon Laboratory is a centre for the high field testing, notably $J_c(B)$, of practical superconductors for use in magnet construction. With the advent of high temperature superconductors we have turned our attention to the problems of performing similar tests on samples of bulk high T_c materials. Our justification for this work is that, in all probability, the first usable conductors fabricated in significant lengths will incorporate material in bulk form, albeit textured in some way, rather than, say, thin film or single crystal. This means it will be necessary to test "short samples" in traditional geometries (e.g. coil and hairpin) which will need to carry transport currents (~tens of amperes) introduced by normal electrical contacts. With the help of collaborators from other university depts. and industry, we have obtained the necessary artefacts fashioned from both YBCO and BiSCO and, using these, we have generated data which are proving useful in a number of ways. One example is the correlation of various synthesis routes with $J_c(B)$ values such that the latter may be optimised. In this paper we describe our choice of sample formats, discuss the difficulties encountered and present some of our data as illustration.

16:20 JH-02 High T_c Superconductivity of Bi-Pb-(Te,Se,Sb)-Sr-Ca-Cu-O H. Ohtsuka, T. Akeyoshi, K. Kawasaki and M. Sugahara Faculty of Engineering, Yokohama National University

Seeing the record T_{cmax} of the highest transition temperature T_c of superconductor, one notices that T_{cmax} increases with the increase of the number of constituent elements. In this report we will give the result of experimental study made to improve T_c of Bi-Pb-Sr-Ca-Cu-O superconductor by doping additional elements such as Te, Se, and Sb. The expected effects of the doping are (i) the deformation of the crystal structure with the introduction of atoms with different size, (ii) the modification of electronic state by the dopants of different valance number, and (iii) variation of phonon modes with the lattice deformation and with the mass difference of elements.

The specimens are prepared by the ordinary solid-state reaction method using Bi_2O_3, $(PbCO_3)_2$ $Pb(OH)_2$, $CaCO_3$, $SrCO_3$, CuO and oxides of Te, Se, and Sb. Those mixtures are calcined in air at 800°C for 12 hours and sintered in air at temperatures higher than 800°C. Concerning the dopant of Te, the specimens with the nominal composition of $Bi_{1-X}(Pb_{0.5}Te_{0.5})_XSrCaCu_2O_\delta$ (X=0 ~ 0.5) show that the material acquires the same superconducting properties as Bi-Pb-Sr-Ca-Cu-O even at lower sintering temperature (~845°C) and even in shorter sintering time (~13 hours) when $X \geq 0.1$. On the other hand the addition of Se deteriorates the superconductivity, although the element belongs to the same VIb group as Te. The difference of ion radii (Se^{4+} 0.69Å, Te^{4+} 0.89Å) may responsible for the deterioration. The doping of Sb makes $T_{co} \geq 120K$ just as the best material without dopant and as the best material with Te dopant.

16:40 JH-03 THE DEVICE FOR MECHANICAL TESTING OF HIGH TEMPERATURE (T>77K) SUPERCONDUCTOR AND SUPERCONDUCTIVE SOLENOIDS, V.R.Karasik, M.V.Sidorov; -Lebedev P.N. Physical Institute of the Academy of Sciences of the USSR, Moscow, USSR.

The mechanical strains produced in superconductive magnetic systems(SMS) by the Lourens forces are the main factors depending on their critical parameters and limiting the field of existence. The device of a new type we have constructed is based on thin coil specimen testing. It provides the investigation of relationship between the SMS production technology and the thermomechanical stability under the influence of Lourens forces. The device provides the real stress-strain state modeling in large SMS and it also permits one to investigate strain influence on high temperature superconductor critical current in different magnetic fields. The construction of the device is presented in Fig. 1. The solenoid (3) and the testing coil (4) are fixed by the holding system (2) located on the top of cryostat. The testing coils with the help of shaft (5) can be installed in turn to the central plane of the solenoid. Film specimen of high temperature side of testing coils. The testing external solenoid has internal diameter of 56 sm. and provides maximum magnetic field, of produces up to 500 MPa break in stress in thin coils. Preliminary testing shows high reliability of the device.

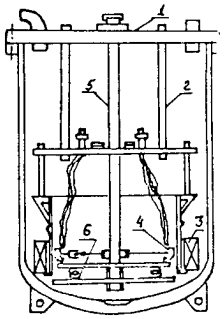


Fig.1

17:00 JH-04 FLUX PINNING CHARACTERISTICS IN SUPERCONDUCTING YBaCuO PREPARED BY THE QUENCH AND MELT GROWTH PROCESS, T. Matsushita, B. Ni, M. Murakami,* M. Morita,* K. Miyamoto,* M. Saga* and S. Matsuda,* Kyushu University, Fukuoka, Japan, *Nippon Steel Corporation, Kawasaki, Japan

The critical current characteristics were measured by the ac inductive method at the liquid nitrogen temperature for superconducting YBaCuO specimens prepared by the quench and melt growth process. The magnetic field was applied in the a-b plane. It was found that there exist two kinds of the current, as observed in sintered ceramics. The bulk critical current density was 1.0×10^8 A/m^2 at 0.12 T and decreased slightly with increasing magnetic field. A uniform current-flow was hindered by nonsuperconducting second phase layers distributed with a mean separation of about 25 μm. This allows us to estimate the local critical current density as 3.2×10^{10} A/m^2 at 0.12 T. Discussion is given on candidates for dominant pinning centers in the specimen and their flux pinning mechanisms. The relation between the critical current density and the observed flux creep rate is also discussed.

17:20 JH-05 THERMAL CONDUCTIVITY AND STABILITY OF SEVERAL HIGH-T_c OXIDE SUPERCONDUCTORS.

K. Noto, K. Mori*, K. Watanabe**, H. Morita**, M. Sasakawa* and Y. Muto**,
Department of Electrical Engineering, Iwate University, Morioka, Japan, *Toyama University, Toyama, Japan, **IMR, Tohoku University, Sendai, Japan

Thermal conductivities in sintered $YBa_2Cu_3O_{7-\delta}$(YBCO), $GdBa_2Cu_3O_{7-\delta}$(GBCO), $Bi_{0.7}Pb_{0.3}SrCaCu_{1.8}O_x$(BPSCCO) and $La_{1.8}Sr_{0.2}Cu O_{4-\delta}$(LSCO) pellets have been measured in order to evaluate the dynamic stability of these high-T_c oxides for the development of practical superconducting wires. The measured thermal conductivities are very small in these materials and it is pointed out that dynamic stabilization such as multifilamentary configuration should be needed for the practical wire development.

The necessity of static (or intrinsic) and dynamic (or MPZ) stabilization was already pointed out theoretically by several authors[1-3]. We have confirmed this point experimentally by the study on thermal conductivity in YBCO and GBCO pellets, and small quench current[4] in $Y_{1-x}Ln_xBa_2Cu_3O_{7-\delta}$ pellets.

In this study, thermal conductivities of BPSCCO and LSCO pellets are also studied and it turned out that they are also very small indicating the necessity of dynamic stabilization in the wires of these materials.

1) D. Ito: Cryogenic Engineering 22 (1987) 383
2) T. Ogasawara: Cryogenic Engineering 23 (1988) 217, 221
3) Y. Iwasa: Proc. 10th Int. Conf. on Magnet Technology (1988)
4) K. Noto et al: Cryogenics (1989) to be published.

AUG. 29 (Tue) Invited Talk Q2 9:00-10:00

9:00	DEVELOPMENT OF ACCELERATOR MAGNETS IN THE WORLD Hall H
Speaker:	C. Taylor LBL
Chairman:	T. Hirabayashi KEK

AUG. 29 (Tue) Invited Talk Q3 10:10-11:10

10:00	PROGRESS IN MAGNETIC RESONANCE SYSTEMS FOR MEDICAL APPLICATIONS Hall H
Speaker:	I. Mano Toshiba General Hospital
Chairman:	F. Irie Kinki Univ.

AUG. 29 (Tue) Session KA (oral) 11:30-12:30

	CRYOGENIC SYSTEMS AND COMPONENTS-1 Room A
Chairman:	H. H. J. ten Kate Univ. of Twente
Cochairman:	E. Tada JAERI

11:30 KA-01 HELIUM: CURRENT STATUS AND FUTURE OUTLOOK, W.B. Fowler, Fermi National Accelerator Laboratory,* Batavia, Illinois

Present activities and further developments in the application of superconductivity depends on the continued availability of helium. The use of higher temperature superconductors will probably not effect the need for helium since in order to attain appropriate current carrying capacity in the new materials liquid helium temperatures may well be needed. World wide use of helium in 1988 is estimated to have been 2.3 to 2.4 x 10^9 std. cubic feet up from 2.1 x 10^9 scf estimated for 1987. The 1989 use is expected to expand by ~10%. On September 30, 1987, 36 x 10^9 scf of helium was in the U.S. storage facility. One has to conclude that even with the estimated 10% annual increase in the use of helium ~10 years of product is in reserve. Using the simplest model where a constant recovery of helium from natural gas accounts for a portion of the yearly use one still finds the U.S. reserve exhausted by the year 2001. A crisis can only be avoided by a less than 10% yearly growth in use or by new extraction plants recovering more helium from natural gas use. Recently the former Reagan administration decided to sell helium assets in an effort to reduce the U.S. budget deficit. The Bush administration and congress are in the process of reviewing this decision, and if they agree one could almost certainly forecast an immediate escalation in the price of helium.

Two new factors important to demand estimates are: 1) The interruption of the space shuttle program in January 1987 reduced the demand for helium by ~10^7 scf per launch. Now with the shuttle activity resumed and more non-manned rockets being used, substantial use by the space program is projected. 2) High energy physics applications continue to expand. The largest projected user will be the SSC Accelerator whose current design calls for an inventory of 52 x 10^6 scf. Projected loss rate is 1/4 per year. A review will be presented covering the trends in other uses, estimation of reserve depletion and availability of new plants utilizing new sources.

* Operated by Universities Research Association, Inc., under contract with the U.S. Department of Energy.

11:50 KA-02 OPERATION PERFORMANCE OF DPCF IN THE TEST OF THE Nb-Ti DEMO POLOIDAL COILS (DPC-U1,U2), T. Kato, J. Yoshida, E. Tada, T. Hiyama, K. Kawano, M. Yamamura, M. Sato, N. Ito, and S. Shimamoto, Japan Atomic Energy Research Institute, Ibaraki, Japan

DPCF [1] is a large cryogenic system for testing Demo Poloidal Coils (DPC)[2] which are superconducting pulsed-coils to investigate superconducting pulse-coil technology required for Fusion Experimental Reactor (FER). This system, which is composed of a newly developed cryogenic pump system, vapor cooled leads (30kA), a liquid helium storage tank (20,000 liter), and cold recovery tank (1m^3), can produce supercritical helium with a mass flow rate of more than 350 g/s at 10 bar below 4K. In this test, the DPCF is firstly operated with a practical coil system. This paper describes thermodynamical performance of the system including an actual forced-flow cooling conductor (cable-in-conduit conductor).

1) E. Tada, at al., 'Performance test results of cryogenic system for Demonstration Poloidal Coil', ICEC-12, Southampton, England (1988)

2) H. Tsuji, at, al., 'Design selection for the fabrication of the Demonstration Poloidal Coil', Fusion Technology, Vol. 10 No.3 (1986) 1518

12:10 KA-03 HELIUM REFRIGERATOR OF SUPERCONDUCTING MRI MAGNET, T. Inaguchi, M. Nagao, and H. Yoshimura, Central Research Laboratory, Mitsubishi Electric Corp., 1-1, Tsukaguchi-Honmachi 8 chome, Amagasaki, Hyogo, Japan

This paper describes design study of cooling systems with the helium condensable Gifford-McMahon (G-M) cycle refrigerator for superconducting MRI magnet. A superconducting MRI magnet requires a cooling system used helium refrigerators in order to reduce supply of liquid helium. The author have achieved no-load temperature of 3.3 K and succeeded in helium liquefaction by the three-stage Gifford-McMahon cycle refrigerator. The key point of the success is the selection of GdxEr(1-x)Rh compounds as regenerator materials. This G-M cycle refrigerator is suitable for a refrigerator of a superconducting MRI magnet because it can condense helium and is much more tractable than a helium refrigerator which include Joule-Thomson loop. Several cooling systems utilizing the G-M cycle refrigerator are studied.

AUG. 29 (Tue) Session KB (oral) 11:30-12:30

IMAGING MAGNETS-1
Room B

Chariman: S. Han
Academia Sinica

Cochairman: T. Hamajima
Toshiba

11:30 KB-01 COMPACT SUPERCONDUCTING MAGNETS FOR MAGNETIC RESONANCE IMAGING, M. Saeki, S. Suzuki, N. Saho, T. Miyajima, Hitachi, Ltd., Ibaraki, Japan

Magnets for medical Magnetic Resonance Imaging (MRI) represent the first large scale commercial application of superconductivity. These devices have required advances in the areas of cryogen consumption, field stability, field homogeneity, transportability, shielding, reliability, and the user interface. We have developed compact 0.5T magnets for those requirements. The design concepts of this magnet are :

(1) Magnet dimensions should be minimized to be 1.6m cube with iron shield.
(2) Liquid helium consumption should be minimized to be less than 50 cc/hr.
(3) To use double radiation shields without using LN2.
(4) Radiation shields should reduce the raise of helium consumption during the gradient coils operation without large eddy current effect.
(5) Fully welded leak-free cryostat without elastomer seals
(6) Refrigerator turret should minimize the raise of refrigerator operating noise.

11:50 KB-02 SUPERCONDUCTING MAGNETIZATION AS THE CAUSE OF FIELD ERRORS AND FIELD DRIFT IN NMR-MAGNET, P. Turowski, Th. Schneider, Kernforschungszentrum Karlsruhe, Institut für Technische Physik, 7500 Karlsruhe, FRG

The magnetization of the superconducting filaments is the cause of the residual fields in superconducting magnets. The residual field in a solenoid has a field distribution along the z-axis completely different from the field distribution of a solenoid. It shows a maximum field at both ends of the coil and a minimum field in the center of the coil. This is an effect of the negative slope of the magnetization of the superconductor versus the magnetic field. A computer calculation of the residual field with the assumption of a negative slope of the magnetization has given qualitatively the field pattern which has been observed. The magnetization of superconductors decays versus time in a logarithmic scale due to flux creep phenomena which could be confirmed by the decay of the residual field of a superconducting magnet. In the case of a superconducting magnet short circuited by a superconducting switch the decaying magnetization induces a transport current generating a solenoidal field. This induced field shows corresponding to the decay of the magnetization also a logarithmic time behaviour. The decay of the magnetization can be accounted to the decay of the screening currents in the filaments and this would lead to a resistivity in the superconductor in the range of 10^{-23} Ωm.

12:10 KB-03 THE COIL DESIGN OF THE NEW SUPERCONDUCTING MRI MAGNET M. Fujita, T.Take, Fuji Electric Corporate Research and Development Ltd., Chiba, Japan

This paper describes a coil design of a superconducting MRI magnet, which is the type of super magnetic shielding, for imaging a human body. The high homogeneous magnetic field and leakage fluxes from the magnet are very important problems at the coil design stage. A CAD program has been developed to optimize the coil configurations of highly homogeneous, rotationary symmetrical magnets in the presence of the cancelling coils and iron yoke for shielding leakage fluxes. The main coils are constructed by 3 pair ring coils and the cancelling coils are by 2 pair ring coils. In order to reduce leakage fluxes from the magnet, the ratio of the amper-turn between the main coils and the cancelling coils must be set, considering the magnetic moment $I*r^2$.(I: amper-turn, r:coil radius) The magnetic field induced by the iron yoke is analyzed with the axis-symmetrical magnetic moment method which is one of integral equation methods. Furthermore in order to obtain the high homogeneous magnetic field over the imaging space, the main coil configuration must be reset to compensate the inhomogeneous magnetic flux density components induced by the cancelling coils and iron yoke up to 10th order component along the symmetrical axis. As the iteration of the optimal coil configuration, the Newton-Raphson method are applied. As the calculating results of the superconducting MRI magnet with the diameter of the warm bore 800mm and flux density 1.5T, the 5 G area is 56m² and the magnetic homogenuity over the 35cm DSV is 1 ppm within the limit of the weight of iron yoke, 10 ton. These results are very good for MRI system.

AUG. 29 (Tue) Session KD (oral) 14:00-15:40

HIGH Tc SUPERCONDUCTORS-3
Room A

Chairman: V. R. Karasik
Levedev

Cochairman: N. Maki
Hitachi

14:00 KD-01 AC LOSSES IN OXIDE SUPERCONDUCTORS, M. A. Hilal and J. D. Lloyd*, Applied Superconductivity Center, University of Wisconsin, Madison, WI 53706, USA

Oxide superconductors have certain unique characteristics as compared to low temperature superconductors. The anisotropy of the critical current density in particular will impact the eddy current distribution and losses in composite conductors. The oxide superconductors also have transport critical current densities lower than the magnetization current densities which make the hysteric loss models more complicated as compared to low temperature superconductors. The study of both eddy current and hysteric losses of oxide superconductors will be presented. Oxide superconductor motors will be considered as an example for applying the developed model losses.

*Emerson Motor Technology Center, Emerson Electric Co., St. Louis, MO, USA

14:20 KD-02 CHARACTERISTICS OF SUPERCONDUCTING Y-Ba-Cu-O FOR MAGNETIC SHIELDS, M. Itoh, H. Ishigaki, T. Ohyama*, T. Minemoto*, M. Motokawa* and H. Nojiri*, Kinki Univ., Higashi-Osaka, Japan, *Kobe Univ., Kobe, Japan.

We have been studying the fabrication of superconducting Y-Ba-Cu-O for purposes of applications to magnetic shields, magnetic bearings and sensing devices. In this study, we systematically tried to improve the electrical and mechanical properties by changing compression pressure in the process used in forming a pellet and by adding Ag powder (1-7 wt%) to Y-Ba-Cu-O powder, for magnetic shielding.

Low critical temperature Tc materials used here showed presence of carbon much higher than high Tc materials by XPS analysis. Tc and current density Jc became lower with an increase of impure gas (carbonic dioxide or carbonic monoxide) in air. Pure air (N_2:O_2=7.9:2.1, 99.999 %) was therefore used in this experiment. Tc of materials containing Ag became higher than non-containing materials. The grain size of Ag particles (99.99 %) was about 20 μm or smaller. Crystal structures of higher Tc materials were confirmed as $Y_1Ba_2Cu_3O_7$ by X-ray diffraction analysis.

Density, hardness, Tc and ratio of resistivity at 300 K to resistivity at 100 K became higher with increases of compression pressure (0.05-1.0 GPa). On the other hand, we have measured the resistance of Y-Ba-Cu-O as a function of magnetic fields (0-30 T) in 4.2 K and 77.4 K.

The superconducting cylinders were prepared by using superconducting Y-Ba-Cu-O powder, pressing it at a compression pressure of 0.4 GPa, and then sintering it in flowing pure air. The present paper also examines the effect of magnetic shields on the cylinder.

14:40 KD-03 Bi(Pb)-Sr-Ca-Cu-O SUPERCONDUCTING TAPES PREPARED BY DOCTOR-BLADING PROCESS, H. Kumakura, K. Togano, D.R. Dietderich, H. Maeda, E. Yanagisawa* and T. Morimoto*, National Research Institute for Metals, Ibaraki Japan
*Asahi Glass Co. Ltd., Yokohama Japan

Thin tapes(~30μm thick) of high-T_c Bi(Pb)-Sr-Ca-Cu-O superconductor have been successfully fabricated by the combined process of doctor blade casting, cold rolling and sintering. Transition temperature T_c(zero resistance) above 105K was easily obtained for these tapes. Tapes were composed mostly of high-T_c phase with small amount of low T_c phase. Tapes have an oriented microstructure with the plate-like grains having their c-axis perpendicular to the tape surface. This oriented microstructure together with the increase in packing density by the rolling improved the coupling nature of grains and hence, critical current density J_c above 2000A/cm² at 77K and zero magnetic field. The tapes are flexible and can be bent up to the bending strain ~0.12%, which is much larger than that of the conventionally sintered materials. This flexibility of the tapes comes from their dense and oriented microstructure. J_c is almost constant up to the bending strain ~0.11%, but it drops rapidly just before fracture. This insensitivity of J_c to strain is encouraging for future application of Bi-oxide conductors in superconducting coils.

15:00 KD-04 SURFACE MODIFICATION BY CO2 LASER AND SURFACE CURRENT CONCENTRATION OF OXIDE SUPERCONDUCTOR H.Nomura* M.Okutomi* A.Kitagawa** & T.Onishi*
*Electrotechnical Laboratory,Tsukuba,Japan
**Hitachi-Zosen Research & Incorporation, Osaka, Japan
Properties of oxide superconductors are very sensitive to their surface condition. We report here the results whether these kinds of superconductors do change or not their properties by the irradiation of CO2 laser beam onto their surfaces. Mainly we prepered two kinds of materials. First was $YBa_xSr_{2-x}Cu_3Oy$ sintered with SrO within $1.6 \leq x \leq 2.0$, where it showed superconducting state. Other superconductor was YBa_2Cu_3Oy well-mixed and sintered with 20 wt% Ag powder for non-reactional metal. Laser beam was irradiated by changing of scanning speed to the sample surface . The workpiece surface was blown by oxygen gas during the irradiation. After the irradiation, surface of the material was studied and found both superconducting and non-superconducting phase. We also report here,a unique phenomenon of the dependency between current path and the laser traces.If the current is parallel to the laser traces, superconducting or metalic phase is observed, while the current is built up perpendicular to the traces, semiconducting property is observed. Ag impregnated sample showed much dependency of current concentration on the surface of the conductor. But after the irradiation, this sample showed amorphous property in some cases.

15:20 KD-05 HIGH-Tc SUPERCONDUCTING FILMS OF Y-Ba-Cu OXIDES PREPARED BY A LOW-PRESSURE PLASMA SPRAYING, K.Tachikawa*, Y.Shimbo**, M.Ono**, M.Kabasawa**and S.Kosuge**, *Tokai University, Hiratsuka, Kanagawa, Japan, **NKK Corporation, Kawasaki, Kanagawa, Japan
Superconducting thick films of Y-Ba-Cu oxides with zero resistant temperature (Tc) of 90K has been prepared by a plasma spraying in low pressure oxygen atmosphere, and a new reaction method has been developed to improve the critical current density (Jc) of the films. An oxide layer richer in Ba and Cu was sprayed on a $YBa_2Cu_3O_x$+Y_2BaCuO_5 mixed layer sprayed previously on a substrate. During post annealing in oxygen at 930 - 970℃, the oxide layer richer in Ba and Cu melted. The molten oxide diffused into the underlying layer, and acted as a flux which enhanced the grain growth of $YBa_2Cu_3O_x$.The excess flux reacted with Y_2BaCuO_5 to form $YBa_2Cu_3O_x$. These reactions yielded a dense single phase $YBa_2Cu_3O_x$ layer and improved the Jc of the film up to 1500A/cm²(77K,0T). Magnetic shielding tubes were prepared by this technique. A $YBa_2Cu_3O_x$ layer was formed on the outer surface of a Ni plated Cu tube 18mm in diameter and 140mm in length. Magnetic shielding performance was evaluated by applying a.c. magnetic field in the axial direction of the tube.A perfect magnetic shielding was achieved until the applied field reached several gauss.

AUG. 29 (Tue) Session KE (oral) 14:00-15:40

INSTRUMENTATION AND MEASUREMENTS-2
Room B

Chairman: B. L. Weintraub
LANL

Cochairman: Y. Takahashi
JAERI

14:00 KE-01 DIPOLE AND QUADRUPOLE FIELD MEASUREMENT TECHNIQUE UTILIZING THE FARADAY ROTATION EFFECT IN FIBER OPTIC CABLES, C. Haddock, M.Y.M. Tong, TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3, Canada.
The development of a magnetic field measurement technique based on the Faraday Rotation effect of light in polarization preserving optical fibers is described. The application of the technique to the measurement of field uniformity and field integral in dipole and quadrupole a.c. and d.c. magnets is presented.

14:20 KE-02 MEASUREMENT OF MAGNETIC FIELD DISTRIBUTION USING THE HIGH SENSITIVE FORCE SENSOR AND ITS APPLICATION TO THE MEASUREMENT OF TWO-DIMENSIONAL DISTRIBUTION OF MEISSNER EFFECT OF SUPERCONDUCTORS, H.Ishigaki, A.Hida and M.Itoh, Kinki Univ., Higashi Osaka, Japan
We have been studying the applications of high Tc superconducting materials to magnetic shields and magnetic bearings. In the process of the study, it was necessary to measure magnetic fields with high spatial resolution. For this purpose, we developed a measuring system for magnetic fields using a high sensitive force sensor. A small piece of magnetic material which was fixed on a ceramic cantilever generated attractive or repulsive forces due to a magnetic field. These forces through the deformation of the cantilever were measured by using an optical displacement sensor. The measuring system was fixed on a X-Y scanning table. This system was applied to measure two-dimensional distribution of magnetic fields with the spatial resolution of 0.1mm. This resolution will be much higher by using the techniques of micromechanics which have been applied in the developments of the atomic force microscope. At present, we are developing a new instrument named "magnetic microscope" that will be able to measure microscopic magnetic distributions in biological cells, magnetic domains, and etc.
A further study was carried out to measure the two-dimensional distributions of Meissner effect of High Tc superconductors. A magnetic material or a small magnetic coil was fixed on the ceramic cantilever. These sensors were scanned on the surface of the superconductor. Repulsive forces due to the Meissner effect were measured by an optical sensor with a mechanism similar to that used in the magnetic field measuring system.

14:40 KE-03 CONSTRUCTION OF HIGH-FIELD UNIAXIAL-STRAIN-EFFECT AND TRANSVERSE-STRESS-EFFECT MEASUREMENT SYSTEM, K. Kamata,* K. Hatano,* K. Katagiri,** T. Okada,** K. Watanabe*** and Y. Muto***, *Hitachi Cable, Ltd., **ISIR, Osaka University, ***IMR, Tohoku University, Japan
A system has been constructed and tested for estimating the uniaxial strain dependence and the transverse stress dependence of critical currents in high-fields for compound superconducting wires, using the 23 T hybrid magnet HM-2 and the 16.5 T superconducting magnet at Tohoku university. The uniaxial or the transverse stress of up to 100 kg and the current of up to 400 A are applied simultaneously to a specimen wire located perpendicular to a magnetic field at 4.2 K. The load is applied to the wire by an AC servomotor through a 100 kg or a 10 kg load cell and a pull rod linked to a lever arm. The AC servomotor is operated by either the load controll or the strain controll, and is capable of generating both the static load and the cyclic load, utilizing the Shimadzu Controller 4825 including a function generator, combined to a program ramp generator. All the loading components are installed within a cylindrical space of 38 mm in diameter, corresponding to the inner diameter of 44 mm for the HM-2 insert dewar. The strain is monitored directly by a clip gauge attached to a movable copper electrode on one side. Loading operation and measurement can be made apart from the magnet during exciting. Test results for some compound superconducting wires will be described.

15:00 KE-04 A NEW MAGNETIC CIRCUIT FOR MAGNETRON SPUTTERING METHOD. H. Goto, H. Sato, and M. Fukuda, Mitsubishi Steel Mfg., Co., Ltd., Tokyo, JAPAN
Magnetron sputtering method is one of the processes of producing thin films, and is widely used for researches and industrial applications. By this method, secondaly electrons, which are trapped near the surface of the target by magnetic field, accelerate the ionization of Ar gas, and deposition rate increase. However, this method has a problem, since the magnetic field is not uniform, secondary electrons are concentrated on an area where intensity of magnetic field is higher. On a planar magnetron sputtering, the partial target erosion is caused by disproportional magnetic field distribution. With the result that the utility of the target decreases and the cost of producing films increases.
To improve this situation, a new magnetic circuit is required which is to make a larger uniform magnetic field. So, we have developed a new type of magnetic circuit, which has large uniform magnetic field area on the target, by providing permanent magnet arrangement. This new magnetic circuit is consist of an "inner magnet" and an "outer magnet", both of which are magnetized vertical to the surface of the target and opposite direction to each other, with an "intermediate magnet" which is magnetized radial and parallel to the surface of the target. In this research, the magnetic field distribution of the new magnetic circuit is compared with that of the conventional circuit. This report tries to show that this new magnetic circuit is very effective in expanding the uniform magnetic field area and increasing the utility of the target.

15:20 KE-05 THE DESIGN OF CAPACITOR BANKS FOR PULSED MAGNETIC FIELDS. Fritz Herlach and Guido Heremans, Katholieke Universiteit Leuven, Celestijnenlaan 200 D, B-3030 Leuven (Belgium).

The design of capacitor banks for generating pulsed magnetic fields is discussed with a view to their use in experiments. Experimental requirements range from long duration pulsed fields with a pulse duration between a millisecond and a second, to megagauss fields with a pulse duration of the order microsecond. Criteria are discussed for selecting voltage, capacitors, internal inductance and resistance, power supply, cabling, devices for voltage measurement, switching and crow-bar. For switching high current at high voltage, ignitrons, spark gaps, solid dielectric switches, mechanical switches and solid state devices can be used. In particular, we discuss different options for the switching of a slow capacitor bank by means of thyristors. One can use either a central switch consisting of a matrix of high performance thyristors, or a large number of low-cost thyristors, each chain of these assigned to a single capacitor or a block of capacitors. The use of individual thyristor chains does have the advantage of providing separation of the capacitors, at the expense of a large number of trigger circuits. We discuss alternatives for the design of the trigger circuits, mainly using optical fibres. One problem is given by the supply of power to the trigger circuits which must be floating at high voltage. For the central switch, trigger circuitry can be more elaborate, e.g. providing a test pulse before each shot and power turn-off after the shot. General safety provisions for the operation of these fairly large capacitor banks are considered; occasionally these are in conflict with experimental requirements.

AUG. 29 (Tue) Session KF (poster) 14:00-16:00

I DETECTOR AND OTHER MAGNETS-1
II ENERGY STORAGE-2
III CRYOGENIC SYSTEMS AND COMPONENTS-2
Room P1 and P2

Chairman: S. Wolff, DESY

Cochairman: K. Hosoyama, KEK

KF-01 Design of a very high field magnet for the very high energy collider experiment at SSC, H. Hirabayashi, A. Maki, S. Terada and K. Tsuchiya, KEK National Laboratory for High Energy Physics, Tsukuba-shi, Ibaraki-ken 305, Japan, T. Akiyama, T. Doi, H. Kakui, and T. Oba, IHI Ishikawajima-Harima Heavy Industries Co., Ltd., Chiyoda-ku, Tokyo 100, Japan

The feasibility of a very high field superconducting solenoidal magnet for the very high energy collider experiment at SSC is investigated. The magnet of 2 m in diameter, 2.5 m in length produces 6 T field at its center. The coil of the magnet has the structure of the multi-layer solenoid in which every layer is wound on its own aluminum bobbin. These bobbins with coil layer are shrink-fitted together to be assembled as a single tight coil. This structure is chosen to overcome strong magnetic pressure and yet to make the coil as thin as possible in terms of the nuclear absorption length in order not to degrade the performance of calorimeters to be located outside the coil. Its mechanical and thermal properties are thoroughly investigated.

KF-02 THE UPGRADE OF MA.RI.S.A. FACILITY FROM 6.5 TO 10 TESLA: DESIGN, CONSTRUCTION PROBLEMS AND PRELIMINARY TESTS, P.Fabbricatore, R.Marabotto(*), R.Musenich, R.Parodi, M.Perrella(*), S.Pepe, R.Vaccarone, Istituto Nazionale di Fisica Nucleare, Genova, Italy and (*) Ansaldo Componenti, Genova.

The facility MA.RI.S.A. is based on a superconducting solenoid (MARISA I) with a maximum attanaible central field of 6.5 Tesla at 4.2 K and 1000 A supply current in a quite large bore: 500 mm I.D. The facility is upgraded by inserting into the basic solenoid a second one (MARISA II), that rises the field up to 8 Tesla at 4.2 K and 10 Tesla at 1.8 K in a bore 380 mm I.D. Mechanical stresses are the main problems of the inner solenoid; the hoop stress is 200 MPa, so that a cylindrical structure shrinking the solenoid is required. Using a stainless steel cylinder the maximum hoop stress can be reduced to 130 MPa without a signifioative reduotion of the clear bore. A further problem is the interaction between the winding and the outer stainless steel cylinder; the friotion due to relative axial motion, after the cool-down or under stress, of the two structures can cause premature quenching. To avoid this occurence, the banding structure of the inner solenoid was design to be anisotropyo i.e. composed by stainless steel and fiber glass thick strips, windend onto the solenoid and vacuum impregnated with epoxy resin. This structure behaves circumferentially like stainless steel but axially like the solenoid winding, so that no thermal stresses take place and, on charging the solenoid, the axial relative stress are reduced of a factor 10. In the paper these design guidelines are discussed together with the description of the -echnical solutions, adopted during the constructic and the preliminary tests.

KF-03 DESIGN AND CONSTRUCTION OF A LARGE SUPER-CONDUCTING SPECTROMETER MAGNET, T. Shintomi and Y. Makida, National Laboratory for High Energy Physics (KEK), and O. Hashimoto and T. Nagae, University of Tokyo, Japan -- A large superconducting spectrometer for Kaon physics is now under construction. The spectrometer is to be installed in a newly built experimental area of a 12 GeV proton synchrotron at KEK. It is intended to have good performances of a large solid angle around 100 m sr and high resolution of 0.1 %. The spectrometer is composed of a superconducting coil and iron yoke with a fan shape. The weight of the iron yoke is about 300 tons. The maximum magnetic field is 3 tesla with a gap of 50 cm and the stored energy is 11.8 MJ at the current of 500 A. As the coil has asymmetric shape, careful considerations have been paid for the design of the magnet structures against the magnetic forces. The magnetic field distributions have been calculated and checked up using two types of three dimensional calculation codes. The coil is supported by a rigid helium vessel made of stainless steel and by a vacuum vessel through supporting rods made from grass fiber reinforced plastic. The fan-shaped superconducting coil is wound with a NbTi/Cu monolithic cable of which copper ratio is 10. It is very difficult to obtain good critical current properties for cables with large copper ratio. Then a superconducting wire of which diameter is 1.0 mm with the copper ratio of 1.0 is imbedded into a groove of copper matrix. The coil is designed to have characteristics of low heat losses of 3 W in consideration of easy operation and maintenance. The superconducting magnet is to be cooled with a refrigerator of ~ 150 W at 4.5 K in consideration of the initial cooling. A small refrigerator is used for a thermal shield at 80 K and thermal anchors of 20 K for supporting structure.

KF-04 AN ULTRA-PRECISE STORAGE RING FOR THE MUON g-2 MEASUREMENT*, F. Krienen, D. Lumba, D. Stassinopoulos, Boston University; G. Bunce, G. Cottingham, J. Cullen, G. Danby, J. Jackson, M. May, J. Mills, C. Pai, I. Polk, A.Prodell, R. Shutt. L. Snydstrup, K. Woodle, Brookhaven National Laboratory; M.S. Lubell, City College of New York; H. Mundzinger, G.Zu Putlitz, University of Heidleberg; K. Nagamine, University of Tokyo; J. Bailey, S.K. Dhawan, A.A.Disco, F.J.M. Farley, V.W. Hughes, H. Jungmann, W. Winn, Yale University; K. Ishida, Riken; K. Endo, H. Hirabayashi, S. Kurokawa, A. Yamamoto, KEK.

An experiment is under construction at BNL for measurement of the anomalous magnetic moment of the muon to very high precision (0.35 PPM). The storage ring contains a 7m radius iron magnet with superconducting excitation coils. The magnetic field should be uniform to $1x10^{-6}$ and the knowledge of the average field around magnetic orbits to ~ 0.1 PPM. Technical details of the magnet yoke, poles, the orbit and coil construction, supports, the cryogenic system, etc, will be given. The methods used to passively and actively correct and control field aberrations will also be given. Methods of measuring the field, both before and during physics running, will be presented.

* Work performed under the auspices of the U. S. Department of Energy.

KF-05 ZEUS MAGNETS CONSTRUCTION STATUS REPORT
A. Bonito Oliva, F. Bordin, O. Dormicchi, G. Gaggero, M. Losasso, R. Penco, N. Valle - ANSALDO COMPONENTI S.p.A., Genova, Italy / R. Bruzzese, M. Spadoni, N. Sacchetti - ENEA, Frascati, Italy / Q. Lin - WORLD LAB, Geneve, Switzerland

The construction progress status of the superconducting magnets for the ZEUS detector (*), to be installed in the HERA e- p ring (DESY, Hamburg), is reported. The first one is a double layer, two densities, aluminum stabilized coil 1849 mm in inner dia., 2487 mm in length and 32.6 mm thick, with a central field of 1.8 T and high particle transparency. The second one is a compensating magnet, wound by a copper stabilized Nb-Ti cable. Its coil has a central field of 5 T, inner dia. 370 mm, a length of 1200 mm and is inserted into a cold iron yoke. The main problems encountered during the large coil construction and the geometrical accuracy obtained are reported. Four splices among the high purity aluminum stabilized cable length were made.
An outer support cylinder, 18 mm thick, was shrink fitted around the coil and then the temporary inner mandrel was removed.
The distribution of mechanical stresses was measured in the different configurations. A large aluminum alloy vacuum chamber with high radiation transparency was built.
A scaled model of the thin solenoid was built and tested. Some results are shown.
The compensating coil is ready to be installed inside its stainless steel cryostat. The cryostat critical features are the high design pressure (20 bar) and the heavy cold mass.

(*) Ordered by INFN Frascati, Italy

KF-06 QUENCH BEHAVIOUR OF A THIN SOLENOID MODEL
A. Bonito Oliva, G. Masullo, O. Dormicchi, G. Gaggero, R. Penco,
ANSALDO COMPONENTI S.p.A., Genova, Italy

A thin superconducting solenoid of 0.76 m in internal diameter and 0.8 m in length has been manufactured and tested by Ansaldo under the ZEUS project contract with INFN*.
It is a model of the ZEUS detector magnet.
The coil has two layers and it is wound with a Rutheford cable stabilized with high purity aluminum (bare dimensions 15x4,3 mm) by LMI.
The coil has an external aluminum cylinder (18 mm in thickness) shrink-fitted around it.
The cooling is ensured by two phase helium circulating in welded aluminum pipe.
The quench propagation velocity and the minimum quench energy have been measured during the tests.
The quench back behaviour has been analyzed.
In this paper we present the measurements and the results obtained by measurements analysis.

* Istituto Nazionale di Fisica Nucleare

KF-07 A MAGNET WITH A HIGHLY HOMOGENEOUS FIELD FOR A FROZEN SPIN POLARIZED TARGET OF PROTON AND DEUTERON, S. Isagawa, S. Ishimoto, K. Morimoto, A. Masaike* and S. Suzuki, National Laboratory for High Energy Physics, Ibaraki, Japan
E. Ban, JEOL Ltd., Tokyo, Japan

In order to operate a polarized target in a frozen spin mode, the target material is moved in a spectrometer from a place with a higher and much homogeneous polarizing field to a place with a lower and less homogeneous holding field commanding a larger scattering angle. Such a frozen spin polarized target was made at KEK, with a large aperture magnet called TELAS (Target Embedded Large Aperture Spectrometer) being used as a spectrometer, to measure various spin dependent parameters of hadron-hadron reactions. The spectometer is C-shaped, total weight, gap and central field of which are 128 tons (weight of coils; 8 tons), 1 m and 0.7 T at the nominal current of 2010A, respectively. Protons and deuterons in a target material are polarized through dynamic polarization process at about 0.25 ~ 0.3 K in a polarizing field of 2.5 T. This polarizing field was prepared in a narrow gap between pole pieces which were additionally placed near the return yoke on pole faces of the main magnet. In order to get high and uniform polarization as well as to measure the polarization with high accuracy, it is essential to prepare the polarizing field as stable and homogeneous as possible. Through a careful design of pole pieces based on flux flow estimation, proper choice of materials and the so-called shimming technique of "cut and try", the polarizing field with a homogeneity better than 1 part in 10^4 could be successfully obtained in pole gap of 95 mm over a useful target volume of 20 mm (height) x 20 mm (width) x 70 mm (length). This paper describes in detail the design, the construction and results of the extensive tests of the pole pieces which provide the TELAS spectrometer with a region of highly homogeneous polarizing field.

*present address: Kyoto University, Kyoto, Japan

KF-08 **WITHDRAWN**

KF-09 PROGRESS OF THE STORAGE RING QUADRUPOLE PROTOTYPE MAGNET FOR THE ADVANCED PHOTON SOURCE*, S.H. Kim, K.M. Thompson, and L.R. Turner, Argonne National Laboratory, U.S.A. This quadrupole magnet requires a maximum field gradient of 20 T/m, an 8 cm diameter aperture, and an asymmetric core geometry to accommodate the vacuum chamber and photon beam pipes. In order to meet the required specifications for the field quality, a prototype magnet is being built to verify the core lamination geometry, the assembly procedures and several design features. A two-dimensional analysis, which includes the effects of the achievable construction tolerances, shows that the multipole coefficients can be kept within the stringent limits. The geometry of the end plates has also been defined on the basis of three-dimensional analysis and field measurements of the prototype magnet. Comparisons between the design calculations and the measurements are presented.

* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

KF-10 DESIGN OF THE SEXTUPOLE MAGNET FOR THE 8 GEV STORAGE RING
J. Ohnishi and S. Motonaga, The Institute of Physical and Chemical Research (RIKEN), Saitama, Japan

A sextupole magnet having correction coils to add a dipole field was designed for the 8 GeV storage ring of a synchrotron radiation source. Sextupole magnets are use to correct the chromaticity and harmonics of the storage ring. In our lattice, moreover, these magnets are required to provide a horizontal or vertical dipole field for closed-orbit correction in our lattice. This lattice has six different families of sextupole magnets. The inside diameter of the sextupole magnets is 110 mm, the length 450 mm and the pole width 90 mm. It is impossible to make return yokes symmetrically because an enlarged vacuum vessel having an extraction space for synchrotron radiation has to be inserted inside the yokes. Required uniform field of sextupole field can be achieved by adjusting the thickness of asymmetrical part of the yokes. The calculated maximum strength of the sextupole field is 360 T/m^2 and field uniformity is within $2x10^{-3}$, inside a radius of 35 mm. The correction dipole field is generated by adding coils wound on the poles and the return yokes. The calculated maximum strength of the correction dipole field is 0.06 T in horizontal and vertical direction with a field uniformity of less than 1% inside a radius of 25 mm. This paper describes the result of the calculation and detailed design of the sextupole magnet.

KF-11 DETERMINATION OF LOADING ORDER OF PERMANENT MAGNET BLOCKS IN THE SOFT X-RAY UNDULATOR (SXU) AT THE NSLS†, M. Kitamura*, L. Solomon**, G. Decker** and J. Galayda**, *Hitachi Research Laboratory, Hitachi, Ltd., **National Synchrotron Light Source, Brookhaven National Laboratory - The Soft X-ray Undulator (SXU), with a period of 8cm, gap range from 3~10cm, 37.5 periods, a maximum on-axis field of about ~.3T, 8 blocks of $SmCo_5$ permanent magnet per period has been developed for installation in the 2.5 GeV electron storage ring at the NSLS. The field errors, most of which are given rise to by magnetization errors in the permanent magnet blocks, and the resulting angular deviation of the electron beam in SXU should be less than a certain tolerance in order to avoid the reduction of brightness of the undulator radiation. To accomplish this, we have studied a method to determine the optimal configuration of the permanent magnet blocks by using the magnet transfer functions. This paper will describe the details of calculation procedure for this method, and characteristics of the measured magnet transfer functions along with comparison with the 2-dimensional field calculations by PANDIRA. Magnetic field measurements performed after loading all the permanent magnet blocks into SXU shows that an almost ideal sinusoidal electron orbit in the midplane of the undulator will be achieved.

† This work was supported under the auspices of the U.S. Department of Energy.

KF-12 A MAGNETIC FIELD ENHANCED 3-D UNDULATOR GEOMETRY*, S.H. Kim and P.J. Viccaro, Argonne National Laboratory, U.S.A. The magnetic field enhancement along the axis of an undulator has important implications for the tunability of the radiated photon energy and the relaxation of the minimum undulator gap for the operation of the Advanced Photon Source (APS). An Nd-Fe-B hybrid undulator geometry of laterally compensated and wedged pole hybrid configuration has been considered. Three-dimensional field calculations of the geometry show that the peak-field enhancement along the axis is about 20% compared to that of the conventional hybrid geometry. Details of the calculations and implications to the tunability of the photon beam in the APS are presented.

* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38

KF-13 DESIGN OF SUPERCONDUCTING WIGGLER FOR A SYNCHROTRON RADIATION FACILITY. K. Aizawa, M. Sakiyama, Y. Yokoyama, A. Iwata, I. Endo^, T. Kasuga^, M. Taniguchi^, M. Tobiyama^, M. Nomura^, Kawasaki Heavy Industries Ltd., Hyogo, Japan, Hiroshima University^, Hiroshima, Japan.

In a synchrotron radiation facility with the intermediate electron beam energy of about 1.5GeV, hard X-ray is provided with the aid of a superconducting wiggler[1,2,3] which generates a magnetic field of more than 4T. The superconducting wiggler is installed into an electron storage ring, and its influence to the life time of the electron beam is the most important problem. In this paper, the designing method of 3-pole superconducting horizontal wiggler where the bending angle, maximum excursion of the electron beam, sextupole component of wiggler field and superconducting characteristics are taken into account is discussed. The typical design of wiggler coils and the whole wiggler system including refrigerator are also reported in this paper.

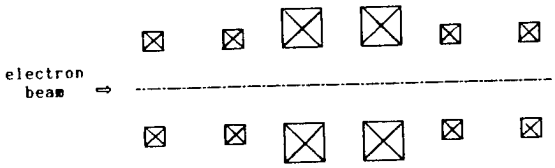


Fig. 1 Schematic layout of superconducting horizontal wiggler coils (3-pole)

KF-14 A SUPERCONDUCTING WIGGLER MAGNET FOR AN ELECTRON BEAM OF 120 MeV. S. Owaki, K. Katagiri, S. Nishijima, T. Nishiura, K. Takahata, K. Seo and T. Okada : I.S.I.R., Osaka University, Osaka, Japan.

We are intending to generate synchrotron radiation (SR) using a 120 MeV electron beam from a linear accelerator combined with a high field wiggler magnet. The higher flux is desirable to obtain SR light of shorter wavelengths (VUV region), because a critical wavelength, characterizing SR spectral distribution, is inversely proportional to the field strength bending the electron beam. A superconducting wiggler magnet was designed for this purpose considering the miniaturization and the economy. The magnet is a three pole vertically deflecting device and each dipole magnet consists of a race-track structure with a superconducting wire of Nb-Ti alloy. The single pair of central poles provides the highest field of 5.0 T, and the two end dipoles, operating at half the amplitude, 2.5 T, with the opposite polarity to the central field, compensate the electron beam on a straight orbit. The magnetic period is 190 mm and the maximum deflected distance of the electron beam, about 36 mm, in spite of the design efforts to minimize their sizes. This is attributed to the too low energy of the electron beam and the high magnetic field. A pure iron yoke is adopted to enhance the field, to support the coiles mechanically and to suppress fringe field, because the orbit of the 120 MeV electron beam is easily disturbed by the fringe field. The critical wavelength is expected as about 300 Å in a VUV region. The design work about the magnet with a cryostat was finished and it is under construction at present. The design concept and the result of its cooling down test are to be presented at this conference.

KF-15 DESIGN AND TEST OF A 6 T SUPERCONDUCTING WIGGLER FOR ADONE IN FRASCATI. A. Aragona, M. Barone, A. Cattoni, U. Gambardella, M. Preger, G. Modestino, C. Sanelli, F. Sgamma, A. Savoia. L.N.F. - I.N.F.N. FRASCATI ITALY. A superconducting wiggler has been designed, built and tested at Laboratori Nazionali INFN in Frascati, Italy, in collaboration with Ansaldo Componenti-Genova, to be used as insertion device in the exhisting storage ring Adone. It will be used as light source on the 1.5 Gev, 100 mA electron beam of the accelerator, to produce about 10^{12} photons/s/mrad in 0.1% bandwidth, at short X ray wavelengths by shifting the emission spectrum caracteristic wavelength. In order to introduce the lowest perturbation on the electron beam orbit and to obtain the simplest phase space distribution of the generated synchrotron light source, (only one bright spot), a facility made up of a s.c. dipole, producing a sharp vertical field peak (6T,12 cm fwhm), placed at center and two side dipoles (0.8T) to compensate the field in such way that the first integral of the vertical field component should vanish, has been manufactured. The s.c. dipole is made up of 2 coils in NbTi, separated by a central plate and kept toghether by two iron yokes of 356Kg of total weight. The magnet gap is 6 cm and the nominal current is 360A. The system is contained in a warm bore cryostat and cooled by boiling helium at 4.6K and 1.4 atm. The static cryostat helium consumption is of 4 l/h and when the cryomagnet is energized it is cooled by a 1430S KOCH liquefier/refrigerator on line with it trough transfer lines. The stored energy is 184KJ. Verification tests have been carried out to confirm the validity of the design. This paper describes the latest status of the design and verification tests.

KF-16 FINAL DESIGN OF A 7.5 T SUPERCONDUCTING WIGGLER MAGNET, * J.-T. Eriksson, L. Kettunen, R. Mikkonen, and L. Söderlund, Tampere University of Technology, Finland

A 3-pole superconducting wiggler magnet is under construction to provide a peak flux density in the excess of 7.5 T in a 0.55 GeV electron storage ring. The field is produced by six NbTi/Cu racetrack shaped coils surrounding iron yokes. An adjustment current is supplied to the end coils to minimize the field integral over the whole field range. 3D field calculations were performed for the optimization of magnet geometry. The mechanical structure designed to counteract the magnetic forces is also discussed. The main objectives have been to keep the period length below 240 mm and the pole gap above 35 mm. The magnet parameters and expected performance will be presented. Integration of the magnet with the associated vertically orientated cryostat is also outlined.

Two model magnets have been built and tested. A linear magnet was built in order to illustrate the problems concerning the 3-pole concept. A one pole winding comprising iron provided information about magnet rigidity in the high field region and also verified the 3D calculations.

* Supported by ASEA Brown-Boveri, Vattenfall Ab, AGA Ab, Scanditronix Ab, Lund's University (Sweden), Imatran Voima Oy, Outokumpu Oy, Huurre Cleanroom Oy (Finland) and Nordisk Industrifond.

KF-17 FIRST RESULTS OF THE START UP PHASE OF THE 2 MVA SUPERCONDUCTING GENERATOR SMG, H.Köfler, F.Ramsauer, Anstalt für Tieftemperaturforschung /FGJ, Styria, Austria, H. Fillunger , ELIN UNION AG., Austria

The superconducting synchronous generator SMG - part of the development program for superconductor application of ELIN Austria - is now ready for acceptance tests for use in a public power-station. The paper will report the final assembly and some of the start up tests done in the laboratory, the generator was manufactured in (ATF). The instrumentation of the rotor with respect to monitoring stationary and transient phenomena in the machine is discussed. The influence of the measuring systems chosen on the running performance is evaluated critically. Furthermore particulars will be given on the preliminary examinations with respect to the refrigeration system for operation of the generator in the public grid. The concept of the refrigeration system is outlined.

Work is jointly funded by ELIN Austria and the Forschungsförderungsfond für die gewerbliche Wirtschaft.

KF-18 DESIGN AND TESTS OF THE SUPERCONDUCTING MAGNET FOR ENERGY STORAGE, T. Tominaga, O. Takashiba and H. Fujita, Chubu Electric Power Company, Inc., K. Asano, Hitachi, Ltd., Japan

A superconducting magnet with a 400 mm coil inner diameter and a stored energy of 1MJ has been built and tested for use of superconducting magnetic energy storage (SMES). The conductor, a compacted strand cable made up of 13 multifilament wires, is a NbTi superconductor containing a copper and a copper-nickel alloy. The coil consisting of 32 double pancake coils with open cooling channels in the horizontal and vertical directions in order to remove the AC loss of the coil are bound with fiberglass reinforced plastic. The magnet is provided for the purpose of investigation of an electric utility transmission stabilization system and various experiments with use of SMES.
This paper describes the design and testing results of this magnet.

KF-19 SECTIONIZING AND OPTIMIZATION OF TROIDAL SUPERCONDUCTING WINDINGS, V.V.Andrianov, A.Y.Arhangelsky, V.V.Zheltov, S.I.Kopylov, M.B.Parizh, Moscow Power Engineering Institute, Institute of High Temperatures Academy of Sciences of the USSR. - -High current toroidal magnetic systems (TMS) are used in the fusion units and inductive energy storages. The major disadvantage of TMS is higher conductor mass applied to the energy stored, compared to solenoidal windings. This parameter can be improved by sectionizing the TMS winding. The sectionizing allows using the superconductor more effectively if current distribution in sections is set so that sections seem to be equally loaded in terms of some criterion. These criteria are current to critical current to critical current ratio, mechanical stresses, deformation of sections or others. We investigated the effect of above mentioned parameters on the TMS optimization. The gain in power capacity may amount to 400% as compared with non-sectionized winding.

KF-20 TESTS OF A CRYOGENIC SYSTEM FOR THE TRISTAN LOW- BETA SUPERCONDUCTING INSERTION QUADRUPOLE MAGNETS, N. Ohuchi, K. Tsuchiya, and A. Terashima ; KEK National Laboratory for High Energy Physics, Tsukuba, Ibaraki, 305 Japan, and K. Shinkai; Kobe Steel, Ltd. , Takasago, Hyogo, 676 Japan. A cryogenic system with subcooled liquid helium was developed for the low-beta superconducting quadrupole magnets that will be used to increase the collision rate of electron and positron beams in the TRISTAN main ring. The cryogenic system consisted of a refrigerator, a subcooler, transfer lines and two magnet-cryostats. The cryogenic system was tested in two ways. In the first test, the capacity of the cryogenic system was measured using dummy loads in place of the two magnet-cryostats. These tests showed that the refrigerator had a capacity of about 170 W, and that subcooled liquid helium was produced at a mass flow rate of 25 g/s, with a pressure of 1.6 atm, and temperature of 4.38 K. In the second test, the cryogenic system was tested with the two magnet-cryostats in place. The two magnets were precooled with parallel cooling channels, and it took about 31 hours for the magnets to be cold. The second test confirmed that the cryogenic system had enough capacity for cooling the two magnets with subcooled liquid helium. This paper describes the temperature and pressure distributions of the cryogenic system, and the characteristics of the subcooled liquid helium.

KF-21 A 12 KELVIN SUPERCONDUCTING MAGNET SYSTEM *, M.T.G. van der Laan, R. Tax, H.H.J. ten Kate, L.J.M. van de Klundert, University of Twente, Applied Superconductivity Centre, P.O.Box 217, 7500 AE Enschede, The Netherlands.

A design study has been made to investigate the possibility of building a superconducting magnet system working at a temperature of 12 K without the need of cryogenic liquids as LHe or LN_2. This can be realized by the application of two double-stage cryocoolers providing cooling solely by conduction. One stage is used for cooling the magnet, the other stage is used for cooling radiation screens and precooling of the magnet. The temperature of the radiation screens will be about 45 K. The magnet is projected to have a warm bore of 330 mm diameter and a length of 700 mm. The field is 1 tesla at a magnet current of 100 A, supplied via retractable leads. The superconductor must be Nb_3Sn. The objective of this paper is to deal with the design considerations, a predesign and lay-out of this magnet system. Other elements in this design are,the application of thermal buffers for cooling the system when the cryocoolers are shortly out of service, thermal switches for coupling and decoupling the cryocoolers and a radiation screen in which a substantial part of the quench energy can be dumped.

* This research in the program of the Foundation for Fundamental Research on Matter FOM has been supported in part by the Netherlands Technology Foundation STW.

KF-22 A CRYOGENIC SYSTEM FOR ELECTRON ANTINEUTRINO REST MASS EXPERIMENT., A.I.Belesev, A.I.Bleule, E.V.Geraskin, A.A.Golubev, N.A.Golubev, O.V.Kazachenko, V.M.Lobashev, B.M.Ovchinnikov, I.E.Yarykin, INR of AS of the USSR, Moscow, USSR.

It is described the operation of the cryogenic system of the electrostatic spectrometer with adiabatic magnetic collimation, intended to measure electron antineutrino mass. The system includes a 100 Wt capacitance refrigerator, which carries out two-phase helium flow circulation through 2 pairs of independent helium cryostats, the distance between them being about 6.5m. The cooldown mass of the cryostats and solenoids is 350 Kg. The total heat rating of the spectrometer with the magnets in operation is 30-40 Wt at the temperature of 4.6 - 4.7 K. The vapour liquid mixture at the pressure 0.5-0.6 atm and with the flow rate 5-6 g/s passes in series all 4 cryostats

KF-23 DEVELOPMENT OF CO-AXIAL TYPE CURRENT LEAD. K. Maehata, M. Wake, N. Sato, T. Fujino and H. Hirabayashi, KEK National Laboratory for High Energy Physics, Ibaraki, Japan

A 800 A co-axial type current lead was developed to supply electric current for high field superconducting hybrid split solenoid magnet. For design of the current lead, a design chart of optimum current leads which has been studied at KEK was used. The material of the conductor is ETP copper. The cross sectional area and the length of the conductor are 40 mm^2 and 800 mm, respectively. The current lead has a rod-in-tube type compact structure. The inner rod and the outer tube perform as lead-in conductors connected to positive and negetive electrodes of the magnet, respectively. The current comes into a magnet from the inner rod and goes out to the outer tube. Since two conductors, each of which has oposit polarity, are assembled co-axially, the current lead can be put into a cryostat through a single connection port. Evaporated helium gas cools both of the conductors flowing in the gap between two conductors from the cold end to the warm end. The two conductors of the current lead have common cooling path, which allows a simple gas flow control. The circular gap is filled with braided glass fiber tapes in order not only to avoid electorical contact between two conductors but also to make the turbulent flow condition of the coolant which makes good heat exchange efficiency between the cooling surface of the current lead and helium gas. The pressure drop of the coolant along the current lead and the heat exchange efficiency depend on the packing condition of the glass tapes. Good operational performance was obtained experimentally. The test results of the heat flow into liquid helium at several different currents were less than 2. 0 mW/A.

KF-24 CURRENT LEADS DESIGN CONSIDERING UNSTEADY STATE T. Yazawa, A. Sato, T. Okamura*, K. Ishito** and S. Kabashima**, Toshiba Research and Development Center, Kanagawa, Japan, *Faculty of Engineering, Tokyo Institute of Technology, Tokyo, Japan, **The Graduate School at Nagatsuda, Tokyo Institute of Technology, Kanagawa, Japan

The authors developed a calculation code for time dependent temperature distribution in gas cooled current leads for superconducting magnets. Usefulness of this code was confirmed through some experiments on model current leads. The code was based on time dependent differential equations for magnet energization process. The authors assumed turbulent flow heat transfer on current leads surface and considered temperature dependence of the material properties of copper and helium into the analysis. Temperature distribution in current leads was found to be considerably susceptible to their dimensions and operating conditions such as energization patterns and gaseous helium flow rate. Therefore, the steady state analysis based on the nominal current was not sufficient for current leads optimization. With this unsteady analysis code, optimized current leads dimensions were obtained for a given operating pattern.

KF-25 Dynamical Adsorption Measurement of Helium Impurities on a Charcoal bed at 77K. H. Yanagi, T. Yabana, K. Fujima and N. Ino, Mayekawa Engineering Research Laboratory, Ibaraki, Japan

A high reliable and stable operation is required for a helium refrigerator, especially for a super conducting generator.
As a result of FMEA(Failure Mode and Effects Analysis), trace-impurities in the refrigerator has found to be decisive for an over-all reliability. The impurity concentration should be reduced far below 0.1ppm by volume.
Hence the high reliability of adsorption bed at low temperature to remove the final traces of impurity is inevitable for a continuous operation of the refrigerator over 10000 hours. But little information is available regarding the dynamical adsorption capacity of adsorbent for the impurities carried in a helium gas stream.
Therefore, we measured the break through curve on a charcoal bed with use of a simulated helium gas mixtures (CO 1ppm, CH_4 1ppm, N_2 5ppm-1000ppm) at 15 kg/cm^2 under the liquid nitrogen temperature. We obtained the dynamical adsorption capacity, q and an over-all mass transfer coefficient, K_{pa_V} necessary for designing of an actual adsorber.

KF-26 **Compensation of Nonlinear Fields in Synchrotrons***, David Neuffer, AT-6, Los Alamos National Laboratory. New methods of correcting dynamic nonlinearities due to the multipole content of the magnets in a synchrotron are presented and discussed. In a simplest form, correction elements are placed at the center (C) of the magnetic transport half-cells as well as near the focussing (F) and defocussing (D) quads. In a first approximation, the corrector strengths follow Simpson's Rule. The F, C, and D correctors may also be used to obtain precise control of the horizontal, coupled, and vertical motion. For example, second-order sextupole nonlinearities can be corrected with F, C, and D octupoles. Generalizations and variations of the method are described and applications to the correction of large nonlinearities in the SSC and LHC superconducting dipoles are discussed. Correction by three or more orders of magnitude can be obtained, and simple solutions to a fundamental problem in synchrotrons and other magnetic transport lines are demonstrated.

*Work supported by the US Department of Energy, Office of High Energy and Nuclear Physics.

KF-27 HIGH PRECISION AUTOMATICALLY MAGNETIC FIELD MAPPING SYSTEM FOR BENDING MAGNET, C. S. Hwang, W. C. Chou, J. H. Huang, M. Y. Lin, Tzuchu Chang, P. K. Tseng, Synchrotron Radiation Research Center, Taipei, Taiwan.

The SRRC MMG has developed a real time data acquisition system to measure the TBA combined function bending magnet and also can measure the other type magnet.This system is include X-Y-Z Table, Hall probe control and data acquisition.The design objective was for a system that was versatile, expandable, easily reconfigurable and modify a better-defined mapping strategy.It can connect with 15 instruments through the GPIB Bus to transmit the signal and control the whole system, THe hardware , software and hierarchical design would be presented.This whole system precision is include position of X-Y-Z Table and stability of Hall probe.For X-Y-Z Table, we must make sure the accuracy of distance, pitch, yaw, vertical and horizontal straightness. For Hall probe, we design a temperature control device to compensate for the changes of the ambient temperature and the temperature change owing to the magnetic field change.Also, the Hall probe need a very stable constant current source.The precision of this system is within 80 ppm.

KF-28 THE TBA PROTOTYPE DIPOLE MAGNET OF SRRC, C. H. Chang, C. S. Hwang, W. C. Chou, J. H. Huang, P. K. Tseng, G. J.Hwang, Synchrotron Radiation Research Center, Taipei, Taiwan.

The SRRC MCG has finished a prototype TBA combined function dipole magnet. The magnet is assembled by 1.5 mm sheet metal of AISI 1006 low carbon steel, which is the laminated core of the magnet.Before assembly, the lamination sheet metal should be shuffled.The stacking fixture can keep the tolerance in the horizontal direction within 0.05 mm.The dipole magnet is a "C" type magnet and has a nominal air gap 50 mm. The air gap , there is a slop which creates a field gradient of 1.6 T/m for nominal field 1.24 Tesla at 1.3 Gev.The magnet length is 1.22 m.The field distribution is calculated by the "magnet" program.The "poisson" program is also used to check "magnet" program.The deformation, pole face and permeability of this dipole magnet has been measured.The TBA combined function bending magnet has been measured.At B(0,0,0) = 1.24 T the absolute value of the gradient is founded to be 0.87% lower than the design value (design value = -1.6 T/m).The effective length of dipole is longer than the quadrupole 70 mm, But using the shim compensation of the end effect, the remaining difference of effective length can be deduced. The DB/B and DG/G also can be measure to compare with the 2-D calculation and also to find the good field region.The measure values are good agreement with expectation and the good field region is about +/- 30 mm.Finally, the dipole effective length of measurement values are predicated by a 3-D calculation.

KF-29 **FIELD INHOMOGENEITY EFFECT ON THE RELATION BETWEEN SHORT SAMPLE CRITICAL CURRENT AND THE QUENCH CURRENT OF HIGH FIELD DIPOLE MAGNETS.**

P.Fabbricatore, R.Musenich, R.Parodi, S.Pepe, R.Vaccarone, Istituto Nazionale di Fisica Nucleare, Genova, Italy

Superconducting cables, for High Energy Physics applications, can experience strong field inhomogeneity (~1 Tesla) when critical current measurements are performed on short samples; this is due to the self field generated by the high current flowing through the cables (up to 10-15 KA). Recent studies showed that the critical magnetic field is not the maximum one at the cable but a lower field (the effective field). The effective field depends on both the maximum field and the cable geometry. A cable composing the winding of a high field dipole magnet experiences magnetic field inhomogeneity higher than the ones of the short sample case (up to 2.5-3 Tesla). In this paper we solved the problem to define both the critical magnetic field of a magnet, connected to the critical current Ic, and the quench current Iq. These critical parameters are related to the short sample values.

KF-30 **WITHDRAWN**

AUG. 29 (Tue) Session KG (oral) 16:00-17:40

HADRON COLLIDER MAGNETS - ANALYSIS AND TEST
Room A

Chairman: R. Yamada
FNAL

Cochairman: M. Wake
KEK

16:00 KG-01 MAGNETIC FIELDS AND LORENTZ FORCES IN AN LHC-DIPOLE MAGNET. 3-D ANALYSIS USING THE FEM PROGRAM TOSCA*.

D. ter Avest*, C. Daum* and H.H.J. ten Kate*. *Applied Superconductivity Centre, University of Twente, The Netherlands, *NIKHEF-H, Amsterdam, The Netherlands.

In superconducting dipole magnets the coil end is usually the most problematic part of the magnet in terms of design, winding and mechanical support. In general it is attempted to design the coil end in such a way that if a quench should occur, it is most likely to take place in the straight section and not in a coil end. This implies that the local magnetic field in the coil ends should be kept lower than the maximum value occurring in the straight section. Also local stress must be limited to meet the above requirement. It is therefore important to have detailed information about the magnetic field and Lorentz force in the coil ends.

This paper describes an investigation of magnetic fields and Lorentz forces in the straight section and the coil end of an LHC-dipole magnet using the finite element program TOSCA. Starting from an existing design of the straight section the constant perimeter description was used to generate the coil end geometry. The choice of parameters in the employed description and the design criteria used as input for the computation will be discussed. Results will be shown of the local magnetic field and Lorentz force in the coil end. These investigations are part of the UT-NIKHEF programme in The Netherlands to develop a 1 meter Nb_3Sn twin aperture dipole model magnet for LHC at CERN Geneva.

*Supported in part by the Netherlands Technology Foundation STW and CERN Geneva.

16:20 KG-02 THREE-DIMENSIONAL COMPUTATION OF MAGNETIC FIELDS AND LORENTZ FORCES OF AN LHC DIPOLE MAGNET USING THE METHOD OF IMAGE CURRENTS.

C. Daum* and D. ter Avest, Applied Superconductivity Centre, University of Twente, The Netherlands. *NIKHEF-H, Amsterdam, The Netherlands.

Magnetic fields and Lorentz forces of an LHC dipole magnet are calculated using the method of image currents to represent the effect of the iron yoke. The calculation is performed for coils of finite length using a parametrization for coil heads of constant perimeter. Fields and forces are calculated as the sum of the fields and forces of the strands out of which the conductors are composed. It is assumed that the strands are parallel to the axis of the conductor and the current is concentrated at the centre of the strands. The field contributions of the strands in the straight part of the magnet are calculated analytically using the Biot-Savart law, those of the coil heads are obtained with the Simpson rule for the integrals in the Biot-Savart law. Results are presented on the field and force distributions in an LHC dipole magnet. A comparison is made with the results of the FEM program TOSCA. These investigations are part of the UT-NIKHEF programme for the development of a 1 meter Nb_3Sn twin aperture prototype dipole magnet for LHC at CERN Geneva.

*Supported in part by the Netherlands Technology Foundation STW and CERN Geneva.

16:40 KG-03 DEVELOPMENT OF A SUPERCONDUCTING SEXTUPOLE-DIPOLE CORRECTOR MAGNET.

A. Ijspeert, R. Perin, CERN, European Organization for Nuclear Research, Geneva, Switzerland, and E. Baynham, P. Glee, R. Coombs, Rutherford Appleton Laboratory, Chilton, England, and J. Wheatley, D. Willis, Tesla Engineering, Storrington, England

Each half cell of the Large Hadron Collider lattice will be equipped with a superconducting corrector magnet which will combine a sextupole and a dipole function. The sextupole coils are designed for operation between - 4000 T/m² and + 4000 T/m². Powered in groups, they will correct for chromaticity as well as for sextupolar errors from other machine elements like the main dipoles. The dipole coils are designed for operation between - 1.5 T and + 1.5 T and will be powered individually to provide a means for orbit corrections. The correction magnets of the two rings will be mounted in pairs in the cryostat of the main quadrupoles. Each pair of side-by-side correction dipoles will correct the horizontal orbit in one ring and the vertical orbit in the other ring and vice versa. The coils are made from solid NbTi superconducting wires. The 0.35 mm wire for the dipole coils is preassembled as a ribbon which is then used for the coil winding. At the ends the individual wires are connected in series. The concentric sextupole and dipole coils are precompressed by shrink-fitted aluminium rings. This coil assembly is mounted in a yoke which basically consists of a simple thick walled iron tube. The paper describes the magnet design, discusses the results of the field and stress calculations especially in view of the effect of the superposition of the two types of field. It comments on the choice of the conductors and describes the developed fabrication techniques.

KG-04 **WITHDRAWN**

17:20 KG-05 DEVELOPMENT OF THE SUPERCONDUCTING BENDING MAGNET FOR THE SR RING, Y. Hosoda, S. Isojima, C. Suzawa, T. Okazaki, T. Masuda, Sumitomo Electric Industries, Ltd., Osaka Japan

The superconducting bending magnets with the bending raduis of 0.5m and magnetic field of 4.15T have been developed. The bending angle is 90 degree so that the 4 magnets are installed in the SR Ring whose size is 3m × 5m. The main coils of the bending magnets are the curvature dipole coils and the conductors are 3-divided key stone type. The shim coils are the epoxy-molded quadrupole coils and installed on the beam duct directly. The designed electron beam energy is 615 Mev and the radiation power from the beam to the magnet is 1kw so that the absorber cooled by Liq. N_2 is setted in the beam duct. This paper describes the design of these magnet and the results of the excitation of them. This project is entrusted by Research Development Corporation of JAPAN.

AUG. 29 (Tue) Session KH (oral) 16:00-17:40

MECHANICAL PROPERTIES AND ANALYSES
Room B

Chairman: W. Maurer
KfK

Cochairman: K. Shibata
Univ. of Tokyo

16:00 KH-01 ELECTROMAGNETIC AND MECHANICAL PROPERTIES OF Nb_3Sn PULSED SUPERCONDUCTING MAGNETS, T. Onishi, H. Tateishi, K. Kaiho, Electrotechnical Laboratory, Ibaraki, Japan, and C. Suzawa, M. Nagata, Sumitomo Electric Industries, Osaka, Japan. The pool-cooled Nb_3Sn pulsed superconducting magnets have been developed. One of them has already been tested and successfully operated upto 8 T in a biased field of 5 T at a rate of 3.4 T/sec. The rating current is 2500 A at 8 T. The conductor used is a Rutherford type cable in which 15 first-level subcables composed of 4 Nb_3Sn wires and 3 copper wires are twisted around Al_2O_3 coated stainless steel strap. It was wound into a magnet in a double pancake fashion before heat treatment and then the magnet was heat-treated. Turn to turn transmission of electromagnetic force was analysed and compared with the experimental results. The calculated values were well consistent with the experimental ones within an experimental error. Ac loss of the magnet was also measured by an electric method and larger than the calculated value, but the reason is not made clear yet. In order to compare the electromagnetic and mechnical properties with those of the above-mentioned magnet and study feasibility of high field pulsed magnet with Nb_3Sn cable, another Nb_3Sn pulsed magnet is now under construction. It is designed to produce 10 T in a biased field of 5 T at an operating current of 2300 A. The designed operating coil current density is fairly high and about 48 A/mm^2 at 10 T. The present paper describes the operating characteristics of the two pulsed magnets and the experimental and theoretical comparisons of their electromagnetic and mechanical properties.

16:20 KH-02 STRUCTURAL ANALYSIS IN CIRCULAR SADDLE TYPE SUPERCONDUCTING MAGNET DESIGN, Wang Qing yuan, Institute of Electrical Engineering Academia sinica, Beijing, China

Structural analysis is one of the important problems in electrical engineering design. In this paper, we first give the assumptions of problem is simplified, and then give the analytical method and results of the stress and deformation of the main structure system of the circular saddle type superconduction magnet, The whole work is completed by a micro-computer, the IBM-PC/AT and SAP-program are used

16:40 KH-03 PLASTIC BENDING LARGE DISPLACEMENT ANALYSIS AND SPRINGBACK OF A CONDUCTOR JACKET OF A SUPERCONDUCTING MAGNET FOR FUSION REACTORS, R. Gori, B. Schrefler, Istituto Scienza e Tecnica delle costruzioni, Padua University, Italy, P. Zaccaria, Progetto RFX, Itit. Gas Ionizzati, Padova, Italy.

Recently proposed preliminary designs of future A15-type force cooled superconductors for toroidal and poloidal field coils for tokamaks present a flat rectangular or a square cross section. As it is well known, relevant plastic deformations occur during the manifacture and winding of cables: a) in the manufacturing process, either in reaction before storage on reel, or in the case of reaction on reel, springback effect (of opposite sense) occur after unwinding; b) during the winding on the bobbin the conductor is deformed from a straight configuration to the shape of the coil, which can present regions with a small radius. This causes a deformation of the conductor cross-section (keystoning) which needs to be controlled as it can cause non uniform areas in the insulation. One way to simulate such behaviour is a numerical analysis of the different forming steps.
In this paper a finite element large displacement elastoplastic analysis is used to model the relevant plastic forming steps and the residual strains and stresses produced by conductor bending during reel unwinding and coil winding.

17:00 KH-04 STRUCTURAL CHARACTERISTICS AND THE INFLUENCE OF MECHANICAL DISTURBANCE IN SUPERCONDUCTING TOROIDAL COILS, Y. Kannoto[1], M. Minami[1], K. Hayakawa[1], H. Hashizume[2], T. Takagi[2] and K. Miya[2]
[1] Mitsubishi Heavy Industries, Ltd. Japan
[2] University of Tokyo, Japan

Superconducting toroidal model coils (inner and outer radii: 350mm and 500mm) designed for SMES were fabricated and tested. The coils are composed of superconductor (Nb-Ti, Nb_3Sn), structural component, stabilizer and insulator. These coil components are united mainly by solder. Cracking or slip may occur in the components under large electromagnetic force or seismic load. For the optimum design of coils, evaluation of the mechanical behavior and the heat generation due to mechanical disturbance is required. In order to establish design guidelines for superconducting toroidal coils, structural analysis and model tests are important.
In this study the mechanical behavior of the coils were numerically evaluated using finite element analysis based on the composite theory.
The model coils were mechanically loaded by the actuator in the cryogenic vessel under 5 ∿ 10 kA current conditions.
Strain, temperature and AE signals of the coil components were measured. This paper also describes the margin for quench when the mechanical disturbance occurs.

17:20 KH-05 TEMPERATURE RISE DUE TO FRICTIONAL SLIDING OF SUS316L VS SUS316L AND SUS316L VS POLYIMIDE AT 4 K, A. Iwabuchi and T. Honda, Iwate University, Morioka, Japan

Frictional heat is one of the source for the quench of a magnet. However, it is uncertain how much temperature rises due to sliding in a magnet. In this work, frictional properties were obtained under the fretting condition between SUS316L steel against the same metal and SUS316L against polyimide at 293, 77 and 4 K. The rise of temperature was measured using thermocouple inserted into a steel specimen at 400 μm below the sliding contact point at 4 K. Friction increases with an increase in fretting cycles due to the removal of the surface oxide layer during fretting for the metal-metal combination at 4 K. The tendency of the temperature rise is similar to that of the friction. Then, a maximum temperature rise during fretting was 9.3 K. While, the friction was rather constant for the metal-polymer combination, and the temperature rise was not so high. The temperature peak appeared twice during one fretting cycle, and time lag was 20 to 50 ms after the sliding velocity reached maximum. The relationship betweem temperature rise and the product of maximum sliding velocity and frictional force shows linear. The difference of the gradient of the relation for two different combinations is explained by the change in distribution rate of the frictional heat. For the metal-polymer combination, much frictional heat goes through the metal specimen. The peak hight of the temperature was increased with an increase in cycles at the begining of the fretting and tends to be saturated.

AUG. 30 (Wed) Invited Talk Q4 9:00-10:00

PROGRAMS FOR MAGNETIC TRANSPORTATION IN THE WORLD
Hall H

Speaker: J. Fujie
Japan Railway

Chairman: T. Okada
Osaka Univ.

AUG. 30 (Wed) Session LA (oral) 10:20-12:00

DETECTOR AND OTHER MAGNETS-2
Room A

Chairman: F. Wittgenstein
CERN

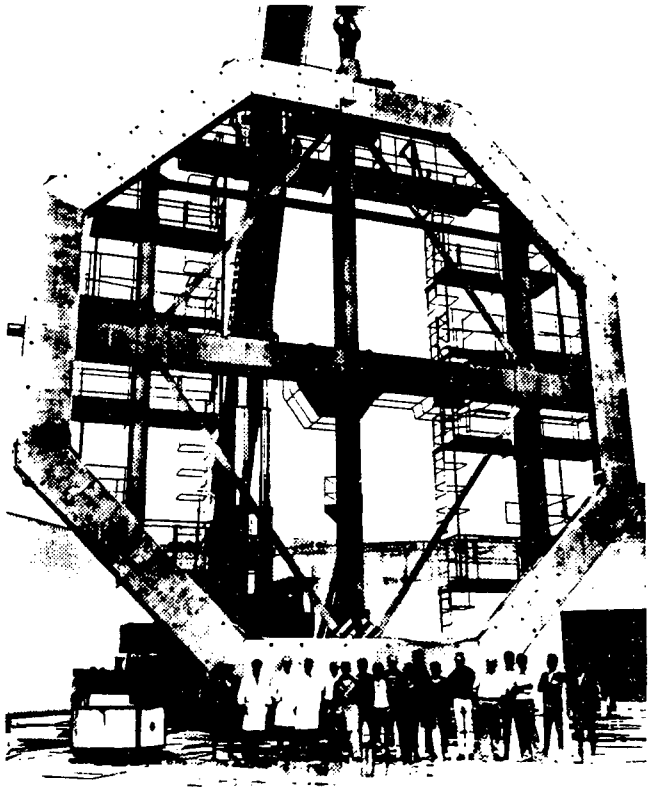
Cochairman: K. Tsuchiya
KEK

10:20 LA-01 THE MAGNETIC DESIGN AND FIELD MEASUREMENT OF FERMILAB COLLIDER DETECTORS: CDF AND DO. Ryuji Yamada, Fermi National Accelerator Laboratory, Batavia, Il., U.S.A.

At Fermilab, there are two major collider detectors CDF and DO, both weigh more than 4000 tons each. The CDF detector is using a superconducting coil, and the DO detector is composed of three major and two small toroidal magnets. The experiences in their magnetic field design and field measurement are described. The computer program TRIM was used for the design of the CDF and the program POISSON for the DO. Both of them are for two-dimensional calculation. For the DO detector, the programs IDEAS and ANSYS were also used for the finite element analysis and for its three dimensional field calculation. These calculations are compared with measured results. CDF detector: The magnetic field distribution inside the CDF solenoid magnet was measured extensively only at the boundaries, and the field values inside the volume were reconstructed using Wind' s method. This method showed an excellent agreement with the inside measured data. the effect due to the return conductor and the effect of joints were measured and discussed. DO detector: The flux distribution inside the yokes and the fringing field of the DO toroids were calculated and compared with measured data. The effects of the small gaps for demagnetization of the yokes are discussed. The magnetic shielding for the beam lines is discussed. A proposal to generate dipole magnetic field inside the DO toroidal magnet is discussed.

10:40 LA-02 **CONSTRUCTION OF THE L3-MAGNET,**
F. Wittgenstein*, A.Hervé*, M.Feldmann*,
D.Luckey**, I Vetlitsky***
*CERN 1211 **GENEVA** 23 Switzerland
MIT **BOSTON MA 02115 USA
***ITEP **MOSKVA** 117259 USSR

The L3 detector, an international collaboration of 36 universities and 13 countries, is installing a new detector on the CERN LEP accelerator.This detector includes an hudge magnet of 8000t and 16m in the diameter. For a central field of .5T, the rated power goes up to a level of 4MW.The magnetized volume is of the order of 1300m^3.The project has been accepted at the beginning of 1983 and operated for its first tests in October 1988. The helicoïdal coil of 1100t of Aluminium plates has been manufactured on the site of CERN in two workshops, specially installed for this purpose. The plates, 60 mm thick, are welded together using the electron beam welding technics. The yoke, about 4000t of Fe-bars, has been machined in Novosibirsk.The poles, about 3000t made of a supporting structure and filling plates, includes 2 moving doors to give access to the inside of the magnet and allow the installation of the different detectors.The total capital cost of the magnet amounts to 24M$.This paper describes the design, manufacturing, assembly and first runs of this magnet.



11:00 LA-03 A SUPERCONDUCTING TOROIDAL MAGNET FOR CHARGED PARTICLE SPECTROSCOPY
J. Imazato, A. Yamamoto, National Laboratory for High Energy Physics, Ibaraki, Japan; H.Tamura, T. Ishikawa, R.S. Hayano, T. Yamazaki, University of Tokyo, Tokyo, Japan; T. Kawaguchi, Mitsubishi Electric Corporation, Kobe, Japan

A Superconducting Toroidal Spectrometer for nuclear- and high-energy-physics experiments has been constructed and tested. This paper reports the design and the performance of the magnet. It comprises 12 sectors of warm iron with 12 superconducting coils in separate cryostats arraged to form a toroidal field. The outermost diameter is 4 m, the inner diameter of field free region is 1.1 m and the total weight is 37 ton. The maximum field produced in each 20 cm air gap is 1.85 T, covering a range of momentum of analyzed charged particles from 100 to 300 Mev/c. Uniformity of the field distribution in the 12 gaps is required, and the long term stability and the reliability of operation are very important as a spectrometer magnet. The coils were wound using NbTi/Cu monolith wire and impregnated with epoxi; winding is cooled by forced flow of two-phase helium of 4.4 K indirectly. Radiation shieldings of 80 K are cooled also by cold helium gas. The total heat load to the two-phase helium is less than 20 w. The operation current is 1550 A and the stored energy is about 3 MJ. The electromagnetic force acting on the coils is supported in each cryostat and the whole iron structure is supported by an outer support ring. Several methods were adopted for the system protection at failures. The magnet was tested and achieved the rated current without quench. Cooldown characteristics, thermal stress, strain at excitation, field distributions, and characteristics at artificial quench were measured.

11:20 LA-04 MEASUREMENTS OF QUENCH PROPAGATION VELOCITY ALONG A SUPER-STABILIZED SUPERCONDUCTOR, A. Devred (SSC Central Design Group, Lawrence Berkeley Laboratory, Berkeley, USA) and H. Desportes (Commissariat à l'Energie Atomique, CEN/Saclay, Gif-sur-Yvette, France).

The construction of large thin-wall superconducting solenoids for high-energy particle detectors has called for the development of super-stabilized superconductors. These conductors consist of a multifilamentary superconductive composite inserted in a large aluminium tape. The transition to the normal resistive state of a super-stabilized conductor is accompanied by a redistribution of current which, due to the size of the normal metal matrix, is long compared to the thermal propagation and greatly affects the propagation velocity. In order to simulate an adiabatic propagation, a two-meter sample of ALEPH conductor, suspended in vacuum and inderectly cooled at its extremities, was tested. Quenches were induced by heaters and velocities were measured using voltage taps. Results are presented of tests at different currents and under different magnetic fields. These results are in good agreement with theoritical predictions.

11:40 LA-05 MAGNET DESIGN STUDY FOR THE TRIUMF KAON FACTORY PROPOSAL, C. Haddock, A. Otter, P. Reeve, M. Harold[3], P. Schwandt[4], H. Sasaki[5], TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3, Canada.

TRIUMF is engaged on a one year predesign study of its Kaon Factory proposal. This proposal calls for a total of 1250 magnets to be installed in three storage rings, two synchrotrons, beam transfer lines and experimental facilities to increase the present beam from 200 μA @ 500 MeV to 100 μA at 30 GeV. The paper discusses the current magnet design status concentrating on the AC Booster and Driver synchrotron ring magnets which will be driven by biased DC current modulated at 50 Hz and 10 Hz respectively. Methods of estimating the core losses for this excitation, the coil eddy current losses, design and fabrication features of prototypes will be presented.

AUG. 30 (Wed) Session LB (oral) 10:20-12:00

STABILITY AND RELIABILITY-1
Room B

Chairman: M. M. Steeves
MIT

Cochairman: K. Okuno
JAERI

10:20 LB-01 RESIDUAL RESISTANCE RATIO - HOW MUCH IS ENOUGH?
J.E.C. Williams, MIT/Francis Bitter National Magnet Laboratory, Cambridge, MA 02139 USA

"Stabilization" of technical superconductors by low resistivity normal metal has long been the accepted methodology. In many applications, however, the superconductor is intrinsically stable and the section of copper (or aluminum) needed is determined predominantly by quench protection. It is instructive therefore to ask under what circumstances is high resistivity ratio necessary or even desirable, bearing in mind that dilute copper alloys have much higher strength than even heavily cold worked copper. Furthermore, dispersion hardened copper can retain significant strength after heating to 700 C, as during the niobium-tin reaction process. There is advantage in the use of other than pure copper or aluminum as the normal component of composite conductors. Two codes have been used to determine the quench process in several hypothetical adiabatic magnets. The first computes the turn-to-turn quench transit time in a conductor with normal metal component of various resistivity ratios for a range of currents and fields. These transit times are reviewed for the information they give about the effect of resistivity on quench propagation. They are also used in a code which approximates quench propagation in a multi-section adiabatic magnet. The results suggest that much stronger copper can be used in the conductor for adiabatic magnets than has been traditional without increasing the peak quench temperatures or voltages to unacceptable levels.

10:40 LB-02 CURRENT DIFFUSION PHENOMENA IN STABILIZER AND STABILITY OF LARGE SUPERCONDUCTING MAGNET, M. Fujiwara, T. Irie, O. Ukai, Y. Mochizuki and K. Hayakawa Takasago Research and Development Center, Mitsubishi Heavy Industies, Ltd., Japan

Large superconducting magnet systems, SMES and so on, are usually designed by the concept of the full stabilization. Dimensions of a stabilizer for a fully stabilized conductor become large and a low resistance material usually adopted as a stabilizer. As the result,a current diffusion coefficient in the stabilizer becomes small and it is anticipated that it takes longer period for the current diffusion in the stabilizer. This time lag of the current diffusion causes larger Joule heating compared with the uniform current condition in the stabilizer, and affects the stability of the conductor and a propagation velocity of normal zone.

In order to study on the current diffusion process in a stabilizer, fundamental tests were conducted. Test elements composed with a stabilizer and a Nb-Ti superconducting wire were used for these tests and the courrent diffusion process was investigated by the artificial normal transition of a Nb-Ti wire.

And, an analytical study on the current diffusion phenomenon was also conducted. The current diffusion process was calculated in the perpendicular section to the current flow of the conductor by a 2-dimensional analysis program.

This paper describes the results of fundamental tests and of the current diffusion analysis, and also describes the test results of the artificial quench test for the model superconducting coil.

11:00 LB-03 PROPAGATION OF NORMAL ZONES OF FINITE SIZE IN LARGE, COMPOSITE SUPERCONDUCTORS.* Lawrence Dresner, Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge, TN 37831-8054, USA

Very large composite superconductors have been proposed for use in energy storage magnets. A typical conductor, rated at 230 kA, is discussed by J. Waynert, Y. Eyssa, and X. Huang, namely, a 6-cm aluminum cylinder with superconducting filaments on its outer surface [*Adv. Cryo. Engr.* 33:187-194 (1988)]. Owing to its large size and nonuniform distribution of filaments, such a conductor can sustain normal zones of finite size that travel at a uniform velocity along the conductor. This paper presents a simple, analytical model that permits determination of the conditions under which such zones can exist, their size, and their velocity. It has been shown that the transport current has a threshold value below which finite normal zones cannot exist and that the propagation velocity corresponding to this threshold current, while not zero, is the smallest possible.

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

11:20 LB-04 QUENCH BEHAVIOR OF HYBRID SPLIT SOLENOID MAGNET M. Wake, K. Maehata, Y. Tsuda(*) and H. Hirabayashi, KEK National Laboratory for High Energy Physics, Tsukuba, Japan and Mitubishi Electric Corp(*), Kobe, Japan.

A superconducting sprit solenoid magnet with central field of 12 Tesla was designed and constructed for the conductor test facility of high field magnets. The magnet is composed of Nb_3Sn inner coil and *Nb-Ti* outer coil. Both coils are arranged so that the direction of the field can be changed either horizontal or vertical in the same cryostat without moving the magnetic center. The splitting mechanism of the magnet allows to remove the inner coil to have large magnetic aperture when used at the central field of 8 Tesla. The inner diameter of the inner coil is 60 mm while the outer coil has the inner diameter of 240 mm. Since the magnet is separated into four parts, the quench characteristic of such a magnet is a little complicated than ordinaly superconducting magnet. The protection of the magnet has to be made avoiding the consentration of the stored energy into single portion of the magnet. The detection of the quench is also not simple if the protection sequece is different by the position of the quench. The measurement of quench phenomena in this magnet was performed with fast A-D converter and multi-task computer system. The obtained data clearly shows how the nomal portion of the superconductor grows in the magnet during a quench. Analysis of the quench data in comparison with the simulation result will be discussed in the paper.

11:40 LB-05 VERY RAPID APPARENTLY NORMAL ZONE PROPAGATION VELOCITY IN HIGH RESISTIVITY MATRIX SUPERCONDUCTING COIL. S. Shimizu and D. Ito, Energy Science & Technology Lab., Toshiba Research & Development Center, Kanagawa, Japan

In order to reduce A.C. losses in A.C. superconducting coils, the authors designed an ultra-fine filamentary superconductor with CuNi matrix, whose resistivity is much greater than that for a copper stabilizer. When a large coil, which is wound with such a conductor, is operated at high current density, the superconductor might be burned out during coil quench. Therefore, quench behaviours were studied in a 50kVA class A.C. coil, which was wound with the conductor. Winding resistance was estimated from terminal voltage and coil current. Since the CuNi resistivity dependence on temperature is small, the normal zone length and therefore apparent normal zone propagation velocity is easily obtained from the resistance time dependence in the coil. When the coil was operated at 50Hz, measured apparent normal zone propagation velocity was 6 km/s, which is much larger than a calculated adiabatic propagation velocity, 10 m/s. When the coil was operated in D.C. conditions, similar behaviour was observed. These results suggest that the extremely large apparent normal zone propagation velocity is due to the high resistivity in the matrix.

AUG. 30 (Wed) Session LC (poster) 10:20-12:00

I HYBRID MAGNETS-2
II IMAGING MAGNETS-2
III INSULATORS AND STRUCTURAL MATERIALS-1
Room P1 and P2

Chairman: N. Mitchell, NET
Cochairman: H. Kobayashi, Nihon Univ.

LC-01 REMOVAL OF DISSOLVED OXYGEN IN COOLING WATER FOR HIGH-POWER RESISTIVE MAGNETS, A. Hoshi, S. Miura and Y. Nakagawa, Institute for Materials Research, Tohoku University, Sendai, Japan

If a water-cooled magnet for a hybrid magnet is burnt out, a superconducting magnet combined with the water-cooled magnet is also destroyed. In order to prevent the expensive superconducting magnet from the failure, the electric resistance of the water-cooled magnet is monitored during the operation of the hybrid magnet so that the water-cooled magnet is renewed immediately when an abnormal resistance decrease is observed. The resistance decrease may be due to thermal and mechanical deterioration of insulator plates. It was also observed, however, that the destroyed Bitter disks and insulator plates were contaminated by copper oxide. The quantity of the copper oxide at a lower part of the Bitter coil was larger than that at an upper part. Usually the burn-out occurs at the lower part of the coil although the temperature is higher at the upper part since the cooling water flows from the bottom to the top of the coil. Thus it is thought that the copper oxide is created from the copper plate and dissolved oxygen in deionized cooling water. The dissolved oxygen can be removed by bubbling of pure nitrogen gas. It was found that the amount of the copper oxide was much decreased when we used the cooling water processed by the nitrogen bubbling. The best condition of bubbling was determined by repeating the experiments. It is expected that a life time of the water-cooled coil becomes longer by removing the dissolved oxygen in cooling water.

LC-02 20 T, ø 130 mm BORE HYBRID MAGNET P. Rub, J.C. Vallier, M. Ohl*, H.J. Schneider-Muntau*

Service National des Champs Intenses, CNRS, BP 166 X, 38042 Grenoble Cedex FRANCE.

* Max-Planck-Institut für Festkörperforschung, Hochfeld-Magnetlabor Grenoble, 38042 Grenoble FRANCE.

We describe a cryomagnetic system designed to produce a steady magnetic field of 20 T in a room temperature bore of 130 mm.

This apparatus is built for experiments concerning the characterisation of significative lengths of superconductors with high H_{c2} and high critical current densities.

The samples could be tested under different stress conditions.

LC-03 **WITHDRAWN**

LC-04 IMPROVEMENTS AND DEVELOPMENT OF HIGH FIELD MAGNETS IN IL. K. Trojnar, A. Borkowski, International Laboratory of High Magnetic Fields and Low Temperatures, Wrocław, Poland. Yu.K. Katrukhin, L.V. Kirensky Institute of Physics, Krasnoyarsk, USSR.

The authors present development of high magnetic fields in International Laboratory and the experience gained in executing and servicing relevant equipment.

The improvement of performance of the three-coil electromagnet providing 20 T field obtained by exchanging the inner coil section is discussed. Elimination of current flow perturbation and decrease of hydraulic resistance in the inner coil could be achieved when the Bitter-type coil has been replaced by polyhelix-type coil. Owing to this, efficiency factor has been improved and the coil cooling conditions have been enhanced as well. Moreover the paper introduces the design and execution of new prospective 10 MW electromagnet for further laboratory being now under erection.

LC-05 THE NIJMEGEN HIGH-FIELD MAGNET LABORATORY: EXPERIENCE WITH THE NEW 30-T HYBRID MAGNET SYSTEM

K. van Hulst, H. van Luong, J.A.A.J. Perenboom, J. Rook and J. Singleton High-Field Magnet Laboratory, University of Nijmegen, Toernooiveld, NL-6525 ED Nijmegen, The Netherlands

The major research-effort at the high-field facility of the University of Nijmegen is in magneto-optical and magneto-transport studies of III-V and II-VI semiconductor materials and devices. Use of magnet-time for the study of intermetallic compounds is growing strongly, and notably concerns research on heavy-fermion systems, quasi-one-dimensional conductors, and conventional and high-T_c superconductors. In fact 1988 has been a record-setting year with respect to magnet-time made available to research groups.

Because of excessive helium-consumption of the new 30-T hybrid magnet system it could not be effectively employed for high-field experiments. During this year extensive modifications on this magnet have come to a successful completion, and after comprehensive testing the magnet is now routinely available for research in fields up to 30 T.

In this paper we will describe the general facilities at our laboratory. We will then discuss in detail the modifications to the hybrid magnet system Nijmegen-II, and present the results of tests and our experience in running the 30.4-T hybrid magnet system.

LC-06 A 1-TESLE SUPERCONDUCTING WHOLE BODY MAGNET FOR MAGNETIC RESONANCE IMAGING, G.J.Zhang, M.H.Lin, H.S.Chen, X.T.Zhou, Q.N.Liu, Y.R.Li,.

A 1-Tesle superconducting whole body magnet system for magnetic resonance imaging completed by KEJIAN CORPORATION LTD. of CHINA. Warm bora diameter is 1.08m, the length of cryostat is 2.55m, total weight of magnet system is 6800Kg with cryostat. The magnet is designed in adiabatical stable, six coils are wound with a 1mm diameter NbTi wire, the rated current is 234A. The central field uniformity is 50ppm/50cm DSV without shim coils, 5ppm/30cm DSV with resistance shim coils. The cryostat system is equipped with LHe and LN_2 refrigerators which have been developed for use with magnetic resonance imaging by GVI.

LC-07 PERMANENT MAGNET WITH HIGH HOMOGENIET, Zhou Rong Zong, Wang Kui Wu, Han Su, Electric Engineering Institute, Academic Sinic of China, Beijing, China.

Magnet is the key part of a MRI apparatus. There are three types of magnet used for MRI: Resistive electromagnet, superconductive magnet and permanent magnet. Among these, permanent magnet has no comsumption of huge electric power and coolant such as helium and it is easy for maintenance as compared with other types. Recently, many hospitals are getting interested in it, and some permanent magnets have developed. Permanent magnet for MRI has a large airgap for inserting the human body, and needs a magnetic field with high homogeneity and stability on the order 10ppm or less. In order to obtain a high homogeneous field, a new magnetic circuit is proposed. In it, so called "main magnetic block", "side magnetis block" and "leakage-blocking magnetic block" are arranged around the gap. In this paper, the theoretic analysis is given. The prototype magnet had brought into success in 1987 at Kejian Corporation LTD. The field strength is 1600 Gs with homogeneity 30ppm over 30cm diameter sphere.

LC-08 INVESTIGATION AND DEVELOPMENT OF PERMANENT MAGNET FOR NMR, Rong Zong Zhou and Weiheng Zhu, Institute of Electrical Engineering and Kejian Corporation, Academia Sinica, Beijing, People's Republic of China.

Magnet is one of the key parts of a NMR system. Permanent Magnet has many features supass resistive electromagnet as well as superconducting magnet, so that many hospitals prefer permanent magnet type NMR systems. The first permanent magnet KJ-1500 for NMR in China had developed in 1987. The whole NMR system ASP-015 with KJ-1500 permanent magnet had completed in 1988 and now producing in small quantity. KJ-1500 permanent magnet is designed with a unique magnetic structure where a high homogeneous magnetic field has been obtained and the material of permanent magnet are fully utilized. KJ-1500 magnet has a vertical aperture of 52 cm with a field strength of 1600 gasses. The homogeneity of the field is 50 ppm over 30 cm sphere. The magnetic circuit and its analysis of the KJ-1500 magnet is described in this paper. The results of measurement is also given and a clear tomogram is obtained.

LC-09 FIELD REGRESSION ANALYSIS OF NMR IMAGING MAGNETS USING A LEAST SQUARES METHOD, X.H.Jiang, S.Han, Institute of Electrical Engineering Academia Sinica, Beijing, China

A least squares method has been developed for the field regression analysis of NMR imaging magnets. The effects of the amount of measured points of field and choice of orders of error fields were studied. It was found that the residual standard deviation of the regression must be 1-2 orders lower than the required homogeneity of field. The result of the regression analysis in the correction of the field of a 0.15T permanent magnet for NMR imaging was quite satisfied.

LC-10 A EFFICIENT METHOD OF REGULATION OF ELECTRICAL SHIM SYSTEM TO CORRECT MAGNETIC FIELD.
P.C.Xia, Institute of Electrical Engineering, Academia,Sinica, P. R. C.

A prototype of magnetic resonence whole body imaging system with a permanent magnet has been built at July, 1988 in China.As is well known,the MRI system requires a very high level of magnetic field homogeneity in spherical region of 30-60 cm in diameter. The very homogeneous magnetic field can be achieved by using a set of electrical shim coils. The construction of shim coils was been described by author. In this paper, a efficient method of regulation of electrical shim system to correct field impurities of various harmonic orders in region of homogeneity of magnetic is described. In this investigstion, the Z-component of magnetic field in region of homogeneity of magnet is expanded in power x,y,z up to the third order terms. Each shim coil corresponds to one term of above expansion. Our method is used to adjusted the currents of shim coils to compensate the inhomogeneities for obtaining a very uniform magnetic field.

LC-11 FRACTURE TOUGHNESS OF A 304 STAINLESS STEEL IN HIGH MAGNETIC FIELDS AT CRYOGENIC TEMPERATURE,
E.Fukusima,S.Kobatake,M.Tanaka, and H.Ogiwara, Toshiba Research and Development Center, Kawasaki, Japan

Elasto-plastic fracture toughness J1c of a 304 stainless steel decreased considerably in high magnetic fields.
To reveal the effect of magnetic fields on fracture toughness, elasto-plastic fracture toughness tests were performed in high fields up to 10T at cryogenic temperatures on 304 stainless steel, which is widely used for superconducting magnets in electric machinery. Tests were made at 77K (0T) and 4K (0T, 5T and 9T), using test facilities which had a 10T-superconducting magnet. In this investigation, the J1c value at 4K, 9T was about 42% lower than the value at 4K, 0T. further data for other austenitic steels and additional discussions are necessary to reveal the mechanism for J1c reduction in high magnetic fields.
This work was performed through Special Coordination Funds from the Science and Technology Agency of the Japanese Government.

LC-12 SUPERCONDUCTING MAGNETS IN HIGH RADIATION ENVIRONMENTS: DESIGN PROBLEMS AND SOLUTIONS*
S.J. St. Lorant, E. Tillmann, Stanford Linear Accelerator Center, Stanford University, Stanford, CA, USA.

As part of the Stanford Linear Collider Project, three high field superconducting solenoid magnets are used to rotate the spin direction of a polarized electron beam. The magnets are installed in a high radiation environment, where they will receive a dose of approximately 10^3 *rads* per hour, or approximately 10^8 *rads* over their lifetimes. This level of radiation and the location in which the magnets are installed, some 10 meters below ground in contiguous tunnels, required careful selection of materials for the construction of the solenoids and their ancillary cryogenic equipment, as well as the development of compatible component designs. This paper describes the materials used and the design of the equipment appropriate for the application. Included are summaries of the physical and mechanical properties of the materials and how they behave when irradiated.

*Work supported by the Department of Energy, Contract DE-AC03M-76SF00 515

LC-13 INVESTIGATION OF IMPREGNANTS FOR SUPERCONDUCTING MAGNETS, D.L.Zha, S.Han, L.Z.Lin, Institute of Electrical Engineering, Academia Sinica, Beijing, China

Several kinds of impregnating materials in common use in China were investigated. We measured the filling effect of paraffin wax beeswax and epoxy resins. Epoxy resin filled with surface-treated silica powder is found to show superior behavior to those of wax and epoxy resin itself as an impregnant. We devepoped a kind of filled epoxy resin, and got the better low temperature properties. A Nb_3Sn magnet was wound in wind-and-react method and impregnated with this filled epoxy resin. The resin was proven easy to use and effective to overcome degradation and reduce training quenches of the magnet.

LC-14 CREEP TEST OF COMPOSITE MATERIALS UNDER IRRADIATION CONDITION, T. Nishiura, S. Nishijima, K. Katagiri, T. Okada, J. Yasuda*, T. Hirokawa*, ISIR, Osaka University, Osaka, Japan, *Shikishima Canvas Co. Ltd., Ohmihachiman, Japan. In the practical environment of the fusion magnet, an insulator is subjected to stress and irradiation at the same time. The large amount of studies concerning radiation damage of composite materials, however, has been carried out in such conditions that the stress and irradiation are applied separately. In order to simulate such fusion magnet conditions for isulator, that is, the fields of stress and irradation can be applied simaltaneously, creep tests on the epoxy based FRP are carried out under γ-ray irradiation. The creep deformation being irradiated during the test was much larger than that tested using the post-irradiated specimen. This result suggests that the radiation damage of FRP in mechanical properties is enhanced by stress and that, therefore, the evaluation of radiation damage using irradiated samples obtained by conventional method can lead to significant underestimation. The mechanism of this enhancement of damage is ascribed to the change of activation energy in the rate process in the chemical reaction between resin and γ-ray.

*This work is partly supported by Grant in Aid for Scientific Research No.63050033, Ministry of Education in Japan.

LC-15 ROLE OF INSULATING MATERIAL ON MECHANICAL BEHAVIOR OF FORCED FLOW SUPERCONDUCTING MAGNETS*- S.Nishijima and T.Okada, ISIR Osaka University, Ibaraki, Osaka 567, Japan--The mechanical behavior of forced flow superconducting magnets has been simulated using small sized insulator-stainless steel systems. The insulation was made using glass clothes impregnated with B-stage epoxy on the stainless steel which simulated the cable conduit . After the insulated stainless steels were stacked, the assemble was cured to form the model windings. The flexural tests were performed on the model windings to investigate the mechanical behavior of the system especially the effect of interface breakage on the macroscopic mechanical behavior of the model windings. The mechanical properties of the insulating layers were also estimated. It was found that the introduction of mechanical defects to the interface between insulator and conduit degraded the macroscopic mechanical properties of the windings. The thermal properties of the windings were also measured.

*This work is partly supported by Grant in Aid for Scientific Reseach NO.63050033, Ministry of Education in Japan.

AUG. 31 (Thr) Invited Talk Q5 9:00-10:00

9:00	PRESENT ACHIEVEMENTS AND PROSPECTS FOR SUPERCONDUCTING TOKAMAKS IN THE WORLD Hall H
Speaker:	P. Komarek KfK
Chairman:	O. Motojima NIFR

AUG. 31 (Thr) Invited Talk Q6 10:10-11:10

10:10	WORLD'S ACHIEVEMENTS IN THE DEVELOPMENT OF SUPERCONDUCTING MATERIALS AT LIQUID HELIUM TEMPERATURE Hall H
Speaker:	K. Inoue NRIM
Chairman:	Y. Nakagawa Tohoku Univ.

AUG. 31 (Thr) Session MA (oral) 11:30-12:30

CONDUCTOR DEVELOPMENT AND FABRICATIONS-1
Room A

Chairman: L. J. M. van de Klundert
Univ. of Twente

Cochairman: M. Takeo
Kyushu Univ.

11:30 MA-01 TRIAL-FABRICATION OF SUPERCONDUCTING RUTHERFORD TYPE CABLE HAVING LARGE KEYSTONE ANGLE

H. Ii, Y. Nagasu and M. Ikeda, The Furukawa Electric Co., Ltd., Tokyo, Japan
T. Shintomi and H. Hirabayashi, National Laboratory for High Energy Physics (KEK), Tsukuba-city, Japan

In the current design of dipole coils used for ultra high energy accelerators such as the Superconducting Super Collider (SSC), wedges are usually inserted into the coils. It is because there is no high Keystone angled Rutherford type cable which enable geometrical configuration for shell structure. In order to improve the mechanical stability of the coils, it is necessary to eliminate the wedges by using Rutherford type cables having larger Keystone angles than the existing ones.
NbTi/Cu strands used for the inner layer cable of the SSC dipole coils were cabled into specific shapes. The strands have a wire diameter of 0.808mm, a NbTi filament diameter of 5 or 6um, and a copper-to-superconductor ratio of 1.3 or 1.5. The fabricated cables have the same width of 9.3mm and the same number of strands of 23 as the currently specified ones. The Keystone angles and the packing factors were changed up to 3 degrees and up to 95%, respectively, while the currently specified ones are 1.6 degrees and 90%. The critical current degradation and the filament breakage were investigated. As expected, the larger Keystone angle and the higher packing factor led to the lower critical current. However, the fabricated cables did not exhibit significant degradation due to cabling. These results showed that the large Keystone angled Rutherford cable can be used for the ultra high energy accelerators where the dipole coiles have no wedges.

11:50 MA-02 ADVANTAGES OF CICC FOR LARGE-SCALE DC MAGNET SYSTEMS, P. G. Marston, A. M. Dawson, J. R. Hale, MIT/Plasma Fusion Center, Cambridge, MA 02139 USA

A new aluminum-sheathed CICC conductor is presently under development at MIT. In addition to the established advantages of CICC conductors, the conductor has unique advantages for DC applications in that internal, cabled superconductor is isolated from mechanical disturbances occurring outside the sheath, the principal source of transient thermal disturbance in these magnets. The aluminum alloy sheath provides sufficient strength to withstand quench-induced high internal pressures and large structural forces within the winding. It also provides thermal mass and high-conductivity normal material required for protection against conductor overheating during a quench transient. It is not necessary for this material to be in intimate contact with the conductor. It should be possible to extrude the sheath continuously around the cable, thereby eliminating seams or joints and allowing manufacture of extremely long lengths of conductor. In addition, the conductor will be advantageous for magnet systems requiring radiation-thin windings such as those required for particle detector magnets. The features of this conductor, its applications and advantages for various magnet systems and its unique stability and protection behavior will be discussed.

12:10 MA-03 MECHANICAL BEHAVIOR UNDER TRANSVERSAL LOAD OF THE 40 kA Nb_3Sn CABLE—IN—CONDUIT CONDUCTOR FOR THE NET INNER POLOIDAL COILS, P. Bruzzone ABB Zurich Switzerland, N. Mitchell NET—Team Garching GFR, J. Kübler EMPA Dübendorf Switzerland

The performances of a high current cable—in—conduit conductor operating in a high field environment are mostly determined by the response of the cable to the internal loads due to the bending stress, the thermal contraction and the Lorenz forces. The mechanical behavior at low temperature of two Nb_3Sn prototype cables, developed at ABB for the poloidal field conductor of NET (Next European Torus), has been investigated at the EMPA lab. Two multistage cables, to be operated at 12.5 Tesla with 40 kA pulsed current, have been manufactured from the same superconducting strand but with a different cable configuration. The influence of different jacket material on the behavior of the cable has been also regarded by encasing the samples into profile sections with different coefficient of thermal expansion (stainless steel and Ni alloy). The residual stress after heat treatment, the cool—down stress, the modulus of elasticity, the response at the maximum operating load and the mechanical hysteresis losses by cyclic load have been measured at 4 K. An analytical model has been developed to correlate the mechanical properties of the cable to the geometrical parameters which can be controlled during the manufacturing process. The good experimental results, supported by a satisfactory analytical model, allow us to optimistic expectations about the performances of the 40 kA Nb_3Sn cable—in—conduit conductor which is now manufactured at ABB for the inner poloidal field coils of NET.

AUG. 31 (Thr) Session MB (oral) 11:30-12:30

CHARACTERISTICS AT PULSED OPERATION-1
Room B

Chairman: J. A. Eikelboom
ECN

Cochairman: T. Ogasawara
Nihon Univ.

11:30 MB-01 DEGRADATION OF THE MAXIMUM TRANSPORT CURRENT IN WIRES AND CABLES CAUSED BY COUPLING CURRENTS, L.J.M. van de Klundert, T.A.W. van Elswijk, A. Nijhuis and G.B.J. Mulder, University of Twente, Enschede, The Netherlands.

When a superconducting multifilamentary wire is placed in an external time-dependent magnetic field its maximum d.c. transport current I_{max} will be smaller than its critical current I_c :

$$I_{max} = I_c \left\{ 1 - \frac{2\,\sigma_t \dot{B} R}{\eta J_c} \left(\frac{\ell_p}{2\pi R} \right)^2 \right\} ,$$

where σ_t represents the effective transverse conductivity of the wire, R the radius of the wire, ℓ_p the twist pitch, ηJ_c the overall critical current density and $\dot{B}$ the applied field rate. The reduction of the maximum current is caused by the fact that part of the filaments, carrying the coupling currents, cannot contribute to the transport current. This principle is also valid for the interstrand coupling currents in cables that are used under conditions with large field rates, for instance in the poloidal field coils of a fusion reactor.

The latter effect was studied experimentally by applying a transverse current to a multifilamentary wire and investigating the reduction of the transport current. The consequences for the design of cables used in coils which generate large $\dot{B}$ are explained by means of model calculations.

11:50 MB-02 AC losses of NbTi Superconductor for a Quick Response Superconducting Generator. Masayuki Nagata, Kazuya Ohmatsu, Hajime Hitotsuyanagi and Maumi Kawashima, Sumitomo Electric Industries, Lts., Osaka, Japan

The most severe magnetic field disturbance to a superconductor by accident for a quick response superconducting generator was estimated from a design of 70MVA superconducting generator. AC losses of the superconductor should be lower than 10kW/m^3 when the magnetic field changes from 4T to 6T at 10T/sec. A composite wire of CuNi/Cu/NbTi was developed, which has 17,300 filaments of 2.5μm embeded in a 0.5mm diameter through a single-stacked billet-making technique. The conductor revealed to have high critical current densities and low losses for the magnetic field changes of $\pm$1T and 2.5Hz with bias field of 5T.
This work was supported by the Energy Conservation Technology Program, one of the Moonlight Projects of MITI, Japan. The project is conducted by "Super GM" with supports of NEDO and supervision of the Agency of Indstrial Science and Technology, MITI, Japan.

12:10 MB-03 EXPERIMENTAL STUDY OF TRANSVERSE RESISTANCE AND COUPLING LOSSES IN SUPERCONDUCTING TRANSPOSED CABLES, V.E.Sytnikov, G.G.Svalov, V.M.Zipunnikov, I.P.Radchenko, A.V.Zlobin, All-Union Cable Research and Development Institute, Moscow, USSR

Authors have investigated problems concerning development and research of superconducting transposed cables, having different transverse resistance. Technique resistance and dynamic energy losses measurements have been described in the paper. Testing results of different cables have been presented, where interwire resistance and corresponding coupling losses have changes in thousand times. Design of the cable with anisotropic interwire resistance was investigated. There are given the criteria of transposed cable designing, which provides fall coupling losses in the cable below hysteresis losses level.

AUG. 31 (Thr) Session MD (oral) 14:00-15:40

FUSION MAGNETS-1
Room A

Chairman: M. Hoenig
MIT

Cochairman: K. Yoshida
JAERI

14:00 MD-01 RELIABLE AND STABLE OPERATION OF THE HIGH-FIELD SUPERCONDUCTING TOKAMAK TRIAM-1M, Y.Nakamura, A.Nagao, N.Hiraki and S.Itoh, Advanced Fusion Research Center, Research Institute for Applied Mechanics, Kyushu University, Kasuga, Japan

The high-field tokamak TRIAM-1M with an Nb_3Sn superconducting toroidal field magnet has been successfully operated for three years since its first operation in June 1986. The achievements obtained by the operation of the superconducting tokamak system are reported here. The toroidal field magnet is composed of 16 D-shaped superconducting coils cooled by pool-boiling helium and assembled into the tokamak system, which is enclosed in a vacuum tank of 4 m diameter. The superconducting magnet system with a cold mass of 30 tons was cooled to 4.5 K in 7 days using a helium refrigerator with a capacity of 460 W. The coils were operated without quenching at currents up to 6202 A, which was the full operating current and produced a maximum field of 11 T at the coil windings. Plasma experiments were carried out with the maximum field and it was confirmed that the coils were stable against magnetic field variations in tokamak operation with a plasma current of 180 kA, including plasma current disruptions. Though the working time of the coils under tokamak environment amounts to about 300 days, we have no serious problem in the superconducting system. On the other hand, the cryogenic system broke down sometimes because of the accumulation of the impurities (CO_2, H_2O etc.) in the heat exchanger at the initial phase of the operation. However, the impurity removal by a large normal absorber enabled us to work the cryogenic system during a long period of 108 days. As a result, the reliable and stable operation of the superconducting tokamak system will encourage design and construction of superconducting devices.

14:20 MD-02 CONCEPT OF CREATION OF T-15 SUPERCONDUCTING MAGNETIC SYSTEM., D.P.Ivanov, E.Yu.Klimenko, S.A.Lelekhov, N.A.Chernopleokov, G.I.Kiknadze -I.V.Kurchatov Institute of Atomic Energy, A.I.Kostenko, I.F.Malyshev, N.A.Monoszon, G.V.Trokhachev, G.F.Churakov - Scientific-Research Institute of Electro-physical Apparatus - Leningrad.

Problems of creation of superconducting magnetic systems for tokamaks are considered in the report. The results, obtained at different stages of design and construction of the largest T-15 toroidal field Sn-Nb-system are analyzed in the report. On the basis of the experience of building up of this device there are discussed the proposals on building up the ITER magnetic system.

14:40 MD-03 FIRST TESTS OF THE T-15 TOROIDAL FIELD SUPERCONDUCTING SYSTEM., V.A.Alkhimovich, I.O.Anashkin, A.N.Vertiporokh, A.N.Volobuev, V.F.Zhulkin, D.P.Ivanov, G.I.Kiknadze, G.M.Kashirskikh, S.A.Lelekhov, I.A.Posadsky, A.N.Safronov, B.A.Stavissky, V.S.Strelkov, P.P.Khvostenko, N.A.Chernopleokov - I.V.Kurchatov Institute of Atomic Energy, Moscow., V.A.Glukhikh, L.B.Dinaburg, M.V.Zhelamsky, A.B.Konstantinov, Yu.A.Konstantinov, A.I.Kostenko, A.D.Malakhov, I.F.Malyshev, N.A.Monoszon, V.P.Muratov, V.I.Peregud, I.I.Sabansky, Yu.V.Spirchenko, G.V.Trokhachev, G.F.Churakov - Scientific-Research Institute of Electro-physical Apparatus - Leningrad. I.K.Butkevich, Yu.I.Dukhanin, S.P.Gorbachov, V.D.Kovalenko, I.M.Morkovkin, N.V.Filin, Tsfassman G.Yu. - NPO "KRIOGENMASH".

Results of the first tests of the experimental plasma device T-15 with a superconducting toroidal magnetic field system are given. After the assembly work was over in October, 1988, the cryostat and working chamber pumping was done; as well as cooling of the system and physical start-up of the device was performed. Under it the magnetic system was transferred into a superconducting state and first plasma was obtained. At present T-15 is being put into nominal working regime (field on torus axis - 3.5 T, on coils -6.3 T, plasma current -1.4 MA). A more detailed investigation of the additional toroidal field coils is given.

15:00 MD-04 Project of Large Helical Device for Currentless Steady Experiment

O.Motojima, J.Yamamoto, K.Yamazaki, N.Ohyabu, T.Mito, M.Fujiwara, A.Iiyoshi

The engineering design study on the Large Helical Device is reported. The basic design parameters are m=10, B=4T, R=4m, a_c=0.96M. The coil systems are composed of ℓ =2 helical coils and 3 pairs of poloidal coils. The total stored energy is more than 2GJoule. The physical objective of this device is to produce currentless steady state high energy plasmas extrapolatable to reactor plasmas and conduct multiple experimental plans to develop fusion research as an alternative approach of tokamaks. The engineering issues in this paper are (1) conductor design, (2) analysis of the electro-magnetic force, (3) support structure design, and (4) refrigeration system design. These items compose the basic design phase II which will develop finally to the detailed design scheduled in 1990. The present design data base are (1) current density is 40A/mm^2 at 8T, and (2) the force level is 1000ton/m. The practical support structure design was developed of which deformation was within 2mm and stress level was within tolerable level ($\sim$ 10kgr/mm^2).

15:20 MD-05 EXCITATION TESTS OF THE FIRST SUPERCONDUCTING HELICAL COIL AS AN R&D PROGRAM OF LARGE HELICAL DEVICE. T. Mito, J. Yamamoto, O. Motojima, K. Takahata, National Institute for Fusion Science, Nagoya, Japan, M. Takeo, Kyusyu University, Fukuoka, Japan, Y. Tuda, Mitsubishi Electric Corporation, Kobe, Japan

We have been developing a superconducting helical coil as a preliminary R&D program of a large helical device. We constructed the first superconducting helical coil and we are going to do its excitation tests from April to July of 1989. The items of the excitation tests are, 1) the excitation tests to the nominal current measuring the stress distribution in the coil, 2) the excitation tests up to the quench point with the measurements of the quench start point, the quench propagation velocities and the temperature distribution after quench, 3) the forced quench tests using a heater with the measurements of MQE, 4) the thermal stability tests to make a comparison between the simple pool boiling and the liquid helium flow-cooling. The coil has many voltage taps, strain gauges and thermometers for the above experiments. The coil is usually cooled with a pool boiling liquid helium but there are nozzles in the liquid helium vessel in order to improve the thermal stability. We expected to remove bubbles in the coil cooling channel by means of the liquid helium spouted out from the nozzles stirring up the liquid in the helium vessel. We will get many data from the excitation tests useful for the design of a large helical device and the results will be presented at the conference.

AUG. 31 (Thr) Session ME (oral) 14:00-15:40

STABILITY AND RELIABILITY-2
ROOM B

Chairman: L. Dresner, ORNL

Cochairman: K. Yamafuji, Kyushu Univ.

14:00 ME-01 ANALYSIS OF FRICTION EFFECTS BETWEEN CASE AND WINDING IN A TOKAMAK SUPERCONDUCTING TOROIDAL FIELD COIL, N. Mitchell, NET-Team, Garching bei Muenchen, FRG, R. Sturt and P. Dallard, Ove Arup and Partners, London, UK

Mechanical effects in superconducting coils have often been observed to have a significant impact on the stability and performance of the coils. These effects generally give rise to local heating in the coil from frictional slip of unbonded components or microcracking of insulation or solder layers, and can cause premature quench of the coil. The proposed toroidal field coils for the Next European Tokamak (NET) consist of a vacuum impregnated superconducting winding contained in a case. The case winding interface is unbonded and under the expected operating conditions relative slip is possible and gaps can open. The analysis of these gaps/slip is rather difficult, since the magnitude is small compared to the elastic displacements but it has a very significant impact on the load paths. The explicit, large displacement finite element code DYNA 3D has been modified to perform the analysis. Analysis of one half of an operation cycle, neglecting dynamic effects, requires about 2 hours of CRAY time. The magnitude and direction of the slip and the resultant frictional heating for the coil have been calculated. It is shown that although with some configurations, time averaged frictional heating can be as great as the estimated AC losses and instantaneous heat inputs can come near the level of the stability margin, design solutions can be found.

14:20 ME-02 TECHNIQUE TO REDUCE DISTURBANCE ENERGY DUE TO FRICTIONAL CONDUCTOR MOTION IN SUPERCONDUCTING MAGNET,* T. Takao, S. Honjo, O. Tsukamoto, Faculty of Engineering, Yokohama National University -- We are theoretically and experimentally investigating frictional conductor motions which are most intricate disturbances causing premature quenches in high-current-density superconducting magnets. To increase the stability of a superconducting magnet, disturbance energy due to conductor motion is to be reduced and to be dissipated before the disturbance energy is transferred to the conductor. In the paper, the relation of the disturbance energy due to conductor motion and winding and conductor structures are quantitatively discussed, and the techniques to reduce the disturbance are investigated. A technique to dissipate the disturbance energy before it is transferred to the conductor is also investigated. We have made an experimental apparatus to simulate conductor motions in the magnet. The apparatus is pneumatically operated and the disturbance energy are measured by measuring the temperature rise and displacement of the conductor. We tested several conductor and winding structures, and investigated the techniques to reduce the disturbance energy. In the experiment, these techniques were verified.

*Research supported by Grant-in-Aid for research, The Ministry of Education, Science and Culture.

14:40 ME-03 STABILIZATION OF WIND AND REACT TYPE EPOXY IMPREGNATED NB3SN INSERT COIL. H.Maeda, H. Ogiwara, M. Sugimoto* and J. Tani*, Toshiba R & D Center, Kawasaki,Japan, * Tohoku University, Katahira, Sendai, Japan

Wind and react processed epoxy impregnated Nb3Sn high field insert coil often shows long sequence of premature quenches before reaching its critical current. Origins of these premature quenches were studied in this paper: A small Nb3Sn insert coil, 67 mm in inner diameter, was wound around a metal bore tube, heat treated and impregnated with epoxy resin. The insert was energized under 7.5 T; the first quench occured at 40 % of Ic on the coil load line, which gradually increased to attain 82% in the 9th run. Based on the voltage and strain signals,the premature quenches were identified to be due to debonding of the coil winding from the bore tube by the electromagnetic force. Sufficiently high radial stress at the interface, during charging, was confirmed by a finite element non-linear calculation by MARC. The second Nb3Sn coil, where the bore tube was dismantled after epoxy impregnation, was designed to eliminate the debonding event during charging the magnet. This magnet attained the critical current without any premature quenches. It is thus demonstrated that the kind of instabilities described above for the Nb3Sn coil is completely eliminated by this procedure.

15:00 ME-04 TRANSIENT HEAT TRANSFER TO HE II UNDER ATMOSPHERIC PRESSURE, K. Lüders, Th. Gradt, R. Wang, U. Ruppert, Freie Universität Berlin

The critical parameters and the stability behaviour of superconducting magnets can be improved by using pressurized superfluid liquid helium (HeIIp) as coolant. Specially for large scale applications cooling with HeIIp is of considerable interest. In view of these applications steady state and transient heat transfer measurements in saturated and pressurized HeII were performed. Single core NbTi superconductors with copper matrix and RhFe wires were used as samples. In the case of transient measurements rectangular current pulses of 0.5 milliseconds duration and longer were applied to the sample while the voltage was detected with a time resolution in the microsecond range. The sample temperature was detected by means of the temperature characteristic of the resistivity in the case of normal conductors and the temperature characteristic of the critical current in the case of superconductors. Data are reported for bath temperatures of 2 K and, in the case of the superconducting samples, transverse magnetic fields of 1.5 T. The results are discussed with regard to the theory of normal zone propagation along superconducting wires.

15:20 ME-05 THE STABILITY MARGIN AND ENERGY DEPOSIT RATE In-Kun Kim and Scott D Peck, General Dynamics Space Systems Div., San Diego, California, U.S.A., The effect of energy deposit rate on the stability margin of a superconducting magnet in subcooled He-II has been predicted. The analysis takes into account both time-dependent Gorter-Mellink heat transport and effects of interfacial Kapitza resistance, and helium phase transition at the interface. For a low rate energy deposit, the conductor temperature stays below current sharing during the disturbance and a portion of helium enthalpy between T_λ and T_{cs} is additionally available for stability margin. For an intermediate rate heat deposit, a He-I layer forms at the interface during the disturbance and normalization takes place but recovery follows. For a disturbance in this category, the maximum stability margin is limited to the enthalpy of He-II up to T_λ. At an extremely high rate of energy deposit, the deposit is almost adiabatic and no recovery is possible if the total energy deposit exceeds a limiting value to be predicted. In this category, only a portion of the He-II enthalpy is available for the stability margin. For the two latter categories, the stability margin is also affected by the Joule heating. Predictions of the limiting stability margin for each category are made for a CICC conductor with extremely high current density(~50,000 A/cm^2 in copper stabilizer) and surface area to volume ratio (~40) and very thin(~0.025 cm) helium layer around the conductor. These predictions are also compared with possible energy deposits during various credible events to assess the stability of the CICC conductor.

AUG. 31 (Thr) Session MF (poster) 14:00-16:00

I CHARACTERISTICS AT PULSED OPERATION-2
II SUPERCONDUCTING GENERATORS AND MOTORS-1
III CONDUCTOR DEVELOPMENT AND FABRICATIONS-2
Room P1 and P2

Chairman: J. R. Heim
LLNL

Cochairman: T. Ando
JAERI

MF-01 CALORIMETRIC MEASUREMENT OF AC LOSS IN Nb_3Sn SUPERCONDUCTORS, M. Takayasu, C.Y.Gung, M.M. Steeves, B.Oliver and M.O. Hoenig, MIT, Plasma Fusion Center, Cambridge, MA 02139 USA. AC loss is a critical factor in the high current density, US-DPC Test Coil , which uses commercial Nb_3Sn wire. AC loss measurements of the 225 strand, 30 kA US-DPC conductor will be carried out in early 1990 at the Demonstration Poloidal Coil Facility (DPCF) at JAERI, Japan at ramp rates of up to 9.5 T/s. In order to perform laboratory measurements, an isothermal calorimeter was built at MIT in which AC loss is measured as a function of boil-off Helium. The paper reports on experiments in which a 12 m long single strand sample wire was wound on a 100 mm diameter ceramic, was heat treated and then subjected to inductive heating. Measurements of AC loss were made : (i) by means of high frequency ripple fields at steady DC fields and (ii) by means of triangular wave ramped fields of up to 9 teslas with maximum ramp rates of 1.5 T/s. The RRR of wire thus tested was in the range of 10 to 40. Conclusions drawn from the tests indicate the major component of AC loss to be hysteresis. In the US-DPC, however, the bundle coupling loss will become comparable or even dominant at higher ramp rates , especially if the RRR value were to improve significantly. The paper discusses experimental problems encountered and relates results to theory.

MF-02 DEVELOPMENT OF NbTi SUPERCONDUCTING WIRE FOR AC APPLICATION. T. Kumano*, M. Ichihara*, E. Suzuki*, E. Shimizu**, D. Ito **, I. Takano**, H. Kasahara***, S. Akita***, and T. Tanaka***, NbTi superconductor wires for AC application have been developed, and are characterized by very fine multifilaments, that are effective in reduction an AC loss. The five different sizes of wires by multiple stacking procedure were prepared. These wires consist of Cu-10%Ni matrix and NbTi filaments of 592116 pieces in numbers. The size of wire ranges from 0.87 mm to 0.103 mm in diameter, in which the filament is sized from 0.52μm to 0.061μm in diameter respectively. The critical current (Ic) was measured on all 5 wires and the dependence of critical current densities (Jc) was researched thereby. As the result of this measurement, the value of 1.46×10^4 A/mm^2 at 1 tesla was obtained in filament of 0.071μm after a heat treatment of 200°C × 24 hours, though the Jc value in filament of 0.061μm in diameter was as low as 31 A/mm^2.
The superconducting properties will be further measured and will be reported on MT-11 conference day.
* Showa Electric Wire and Cable Co., Ltd.
** Toshiba Corp.
*** Central Research Institute of Electric Power Industry (CRIEPI).

MF-03 THE ENERGY BALANCE AND AC LOSSES IN SUPERCONDUCTING HOLLOW FILAMENTS WITH TRANSPORT CURRENTS, by J.A. Eikelboom[1], R.A. Hartmann[2] and L.J.M. van de Klundert[2], 1: ECN Netherlands Energy Research Foundation, The Netherlands, 2: University of Twente, The Netherlands. In a superconducting filament which carries a transport current and which is placed in a changing magnetic field energy is dissipated. The two sources of energy are the changing magnetic field which induces the screening currents in the filament and the external power supply which maintains a constant transport current in the filament. The power supplied by these two sources is only entirely dissipated as heat when the current distribution in the filament is stationary. When the current distribution is changing, for example because of an increasing critical current density in a diminishing external magnetic field or when the field variation is still smaller than the penetration field of the filament, then part of the supplied power is stored in the changing current distribution. This stored energy can be extracted from the filament in a later stage of the field change. The sum of the power thus stored and the power dissipated as heat is equal to the total supplied energy. Results of calculations with a numerical model will be shown, for solid as well as hollow filaments with a constant and field dependent critical current density. For the case of a penetrated filament analytical expressions will be derived for the dissipated heat in hollow filaments with transport currents.

MF-04 TRANSVERSE RESISTIVITY OF CABLES, R.A. Hartmann, L.J.M. van de Klundert*, University of Twente, Faculty of Applied Mathematics,
*Faculty of Applied Physics, Enschede, The Netherlands.
A cable consists of a twisted bundle of wires, with a non conducting centre. If a cable is placed in a perpendicular applied magnetic field, then the induced current will not merely flow in the axial direction, but also around the non conducting centre, in the plane of the cross section. Although for this configuration of an insulating centre, the resistance is rather high, and hence the matrix losses low, this transverse current may saturate a number of filaments, without the presence of any transport current, resulting in a degeneration of the transport performance of the cable.
In a previous paper we already calculated the influence of the transverse resistivity in abcense of applied fields and an axial transport currrent. In this paper we will extend the calculations by computing the current distribution, losses, axial and transverse resistivity in presence of an applied time dependent magnetic field, axial and transverse transport current. The numerical method consists of a staggered grid, based on the integral form of Maxwell's equations, and an iteration process based on the non linear constitutive relation between the electric field and current density. The cable is represented by a periodical serie of multifilamentary wires. Each wire consists of normal ansiotropic and superconducting layers, embedded in solder.

MF-05 AN INDIRECT ESTIMATION METHOD OF AN INTER-STRAND RESISTANCE OF SUPERCONDUCTING CABLED-CONDUCTORS, F. Sumiyoshi, S. Kawabata, N. Oohito and T. Kawashima*, Kagoshima University, Kagoshima, and *Fukuoka Institute of Technology, Fukuoka, Japan

A new method was provided to estimate indirectly the inter-strand resistance of superconducting cabled-conductors under an external stress. In this method, the value of the resistance was determined from a comparison of the theoretical values of the inter-strand coupling-current loss in the conductor with the experimental ones. In order to calculate the loss, we solved Laplace's equation over the normal metal region in the conductor by means of the finite element method under the analytically obtained boundary condition. The experimental values, on the other hand, were obtained from the ac magnetization measurement, where the transverse magnetic field, ranging from 10 to 120Hz in frequency, and up to 1.5T in amplitude, was applied to the conductor. This loss measurement was made by using 50kVA ac coil. The present method of the indirect estimation of inter-strand resistance could be demonstrated successively for the cabled conductor with three strands under the tensile stress.

MF-06 EFFECT OF HEAT CAPACITY AND MATRIX RESISTIVITY ON STABILITY OF SUPERCONDUCTOR IN FAST CHANGING FIELDS. E.Yu.Klimenko, N.N.Martovetsky, S.I.Novikov, Kurchatov Institute for Atomic Energy, Moscow, USSR.

Recently developed theory of stability which takes into account smoothed transition of SC to the normal state allowed to obtain some important results. The theory accounted for stable performance of SC wires with high current density at poor cooling and allowed to find limits of SC wires stable performance at different conditions. Stability criteria were mostly founded with an approach of "frozen flux" conditions, i.e. unchanged current density distribution during evolution of thermal perturbation. Theory has been confirmed in series of experiments, still as frequency range for SC wires is spread some evidences for more stable wires behavior than theory predicts are appeared for thin SC wires in fast changing fields. In this paper a stability of SC wire has been analyzed taking into account heat capacity and matrix resistivity and new stability criteria are obtained. It is shown that for thin wires taking into account heat capacity and matrix resistivity the permissible rates of field or current changing are by tens fold higher than permissible rates for "frozen flux" model. The obtained criteria may remove contradictions between the theory and experiments and allow to estimate stability limits in AC and pulsed magnets. It is seen as well that solution of the stability problem for HTSC wires for AC applications will be much more easy due to high heat capacity of HTSC at nitrogen temperatures.

MF-07 SUPERCONDUCTING CABLE FOR BIG MAGNETS OF THE POOL-BOILING TYPE, V. Zenkevitch, A. Vanjushin (Institute for High Temperatures USSR Academy of Sciences, USSR), T. Erkolahti, J. Teuho, V. Vanhatalo, Outokumpu Ltd, Finland

Within the framework carried out in the Soviet Union by the Institute for High Temperatures of Academy of Sciences in the field of using MHD-method for energy forming, a construction of universal high current superconducting cable was developed for especially big magnets of the pool-boiling type. Outokumpu (Finland) familiarised itself with the manufacturing of the cable. The external cross-section of the cable is 16 x 35 mm^2, inside the cable there are channels for better liquid helium cooling of the core which contains filaments of Nb-Ti. With totally insulated broad sides and with narrow sides of the cable covered for 50% in the field of 6T, with an angle of 30 degrees of the broad side to the horizon the recovery current exceeds 17,5 kA. Critical current comes up to 33-36 kA under the same conditions. Calculated values of these characteristics in the field of 8T make up 13,5 kA (minimum) and 16,5 kA correspondingly. The results of electrical and mechanical tests of the cable are presented as well as the information about electrical insulation which is applied to the cable in the production process. Mechanical tests included compression tests on the broad and narrow sides of the cable and also the pulling test. The experiments were carried out at a temperature of 300K and 77K. Great attention was paid to production control during the manufacture of the cable and its components. There are presented statistical characteristics of the parameters which are being measured in the production process of the cable. The output of the cable reaches about 200 tons.

MF-08 EXPERIMENTAL RESULTS OF SUPERCONDUCTOR FOR FIELDWINDING AND DESIGN CONCEPTS OF 70MW SUPERCONDUCTING GENERATOR, A.Ueda, S.Maeda, H.Hirao, K.Mio, Y.Nagata, T.Yamada, M.Morita and H.Yoshimura, Mitsubishi Electric Corporation, Japan

AC losses and critical currents of several types of superconductors were measured to decide specifications of superconductors for the field winding of a 70MW superconducting generator with low response excitation system. Superconductors for the field winding of the 70MW superconducting generator are required to have high critical current density and small AC losses. High current density of the field winding increases flux density of the rotor and enables to make generator size small. Small AC losses of the superconductor decreases temperature rise of field winding due to flux change and increases the stability against quench during power system faults. The superconductors used for the test are compacted stranded cables composed of NbTi-Cu-CuNi strands, and have the same cable size. The cross sectional structure of the strands, copper ratios and strand insulations for tested cables are different. Critical current were measured under the magnetic flux density from 6 T to 8 T and AC losses were measured by the magnetization measurment method. This paper presents the results of the experiment and design concepts of the field winding for the 70MW generator.

MF-09 TEST RESULTS OF MOTORS WITH A SUPERCONDUCTING ROTOR M. Takahashi, K. Arai, M. Satoh, M. Watanabe, N. Takahashi, R. Takahashi, Hitachi Research Laboratory, Hitachi, Ltd., Ibaraki, Japan

Experimental studies of superconducting motors composed of $YBa_2Cu_3O_7$ and Nb_3Sn rotors were carried out to investigate possibilities of a superconducting AC motor. The rotor shapes were cylindrical, cylindrical with axial slits, or reluctance type which had axially extended bars on a FRP rotor body. The rotor outer diameters were 38mm and lengths were 30mm. Each rotor was vertically inserted into a conventional three phase two pole stator, and supported not only by a pivot bearing but also by a teflon plate to reduce the mechanical friction loss.

From the tests, no rotate was observed at room temperature no matter what the stator exciting power. But, when the $YBa_2Cu_3O_7$ rotors were immersed in liquid nitrogen and kept at a superconductive condition, they started to rotate and kept a constant speed with large slip. For example, they rotated smoothly at 70 rpm when the motor was excited by 5 Hz sinusoidial alternating current of input 12.7VA.

Next, a similar test was done with the cylindrical Nb_3Sn rotor. This rotor was confirmed as able to rotate not only at asynchronous speed, but also synchronous speed. Further, once the rotor reached the synchronous speed, it kept a constant speed even if the stator voltage was decreased to a certain level. The starting torque was approximately proportional to the square of the exciting current. These results indicated that the superconducting motor would be able to be driven by magnetic hysterisis phenomena of the superconductor.

MF-10 PRIOR TESTS OF SUPERCONDUCTING TURBOGENERATOR CTG-300 Y.Rybin, I.Filippov, G.Kchutoretsky, Y.Tjurin, V.Varshavsky and S.Stefanovich, Electrosila Institute, Leningrad, USSR

Electrosila began testing of the superconducting turbogenerator rated 300 MW at the test rig. On the first stage the mechanical state of the generator was determined at the rated speed of 3000 rpm. Then the rotor was cooled down with liquid nitrogen. Time of cooling down was 25 hrs. In the course of evaporation experiments the nitrogen flow rate was 2,4 g/s, this corresponds to the heat leak equal to 480 W in the cryostatic zone and is well correlated with the calculated results. During evaporation continued for 10 hrs 90 kg of liquid nitrogen was evaporated from the rotor. The nitrogen flow rate was not changed with the speed variation practically. No change in the vibration state of the cooled down rotor as compared with the original characteristics was observed. Increased leakage of fresh cooling agent was observed. After the helium transfer coupling is modified, the helium tests are expected to perform in 1989.

MF-11 ELECTRICAL POWER SYSTEM STABILIZATION UTILIZING ENERGY IN FILED WINDING OF SUPERCONDUCTING GENERATOR, Y. Mitani, Y. Kowada, K. Tsuji and Y. Murakami, Osaka University, Osaka Japan

The advantages of a synchronous generator with superconducting field winding can be stated as: 1. Reduction in losses, 2. Improved system performance, 3. High-Voltage armature feasibility, 4. Small size and weight, and so on. This paper proposes a new control conception for superconducting generator to improve power system performances more significantly. The superconducting field winding which produces strong magnetic flux has another feature as energy storage. On the other hand, superconducting magnetic energy storage (SMES) is well-known as a stabilizer of power system oscillations. Therefore it seems that the application of stored energy in superconducting generator to the power system stabilization is feasible, however, it becomes problem that the system voltage may fluctuate caused by the varying current of field winding. In this paper, it is proved qualitatively that the stabilization of power swing by using the energy in the field winding circuit of superconducting generator has a possibility of suppressing the voltage fluctuation of power system at the same time. A power system stabilizing control scheme is designed according to this characteristic. Numerical analysis demonstrates the significance of the improved system performances by the proposed control scheme. Specifications of field windings necessary for the stabilization of model power system are evaluated from the results. In the case of 1,120 MVA generator with 10 kA field current, the maximum DC voltage used for the control is about 4,000 V, which corresponds to the evaluated values for the superconducting generator with quick response excitation.

MF-12 SUPERCONDUCTING MAGNETS FOR DISK-SHAPED MHD GENERATORS. REVIEW AND A PREDESIGN*. H.G. Knoopers, H.H.J ten Kate, L.J.M. van de Klundert, P. Massee*, H.A.L.M. de Graaf*, W.J.M. Balemans*. Applied Superconductivity Centre, University of Twente, Enschede and (*) Eindhoven University of Technology, Eindhoven, The Netherlands.

Magnetohydrodynamic (MHD) energy conversion in combination with a conventional steam cycle can improve the efficiency of the energy production of a power plant. The main efforts in MHD-research concerned the linear channels both in open and closed cycle operating mode. However, there are indications that the disk-shaped MHD generator has a better performance in comparison with the linear geometry. Due to its geometry, the disk generator has several advantages over the linear generator, as for example a simpler electrode geometry, a more compact generator configuration and lower construction costs. To a large extent, the reduction of costs can be ascribed to the less complicated construction of the superconducting magnet system. These promising advantages were the main motivation to study the disk shaped generator.
In this paper the magnet systems used in MHD disk generators will be reviewed and a predesign of a compact superconducting magnet system for a 1 MWe demonstration unit using Nb_3Sn technology is presented.

*These investigations in the program of the Foundation for Fundamental Research on Matter FOM have been supported in part by the Netherlands Technology Foundation STW .

MF-13 FUNDAMENTAL DESIGN FOR MEISSNER MOTOR, A. Ishikawa, A. Takeoka, Y. Kishi, Functional Materials Development Center, Sanyo Electric Co., Ltd., Moriguchi, Osaka, Japan

We have developed a new superconducting motor using high-Tc ceramic superconductors. Computer simulations have estimated the capacity of this motor.

The motor output is dependent on the temperture changes and the repulsive force caused by the Meissner effect. We designed a calculation model and simulated to estimate the output. By changing the shape of superconductors, the motor with a radius of 30 mm was calculated to generate a maximum output of 0.03 W, and its rotating speed and torque were 60 rpm and 5gf-cm respectively. Also, the estimation showed that the motor torque depended on a mounting degree of superconducting plates. Superconductors with higher Hc_1 are required to improve the output.

This motor consists of a wheel with superconducting plates in YBaCuO system, a heater above the wheel, liquid nitrogen and a magnet below. The magnet was set near the place where the plates entered the liquid nitrogen. Cooled down in liquid nitrogen, the plates near the magnet are repelled by the magnetic field due to the Meissner effect and this provides the motor with torque. The rotating superconducting plates are heated in turn at the top of the wheel and return to their normal states. We call it the "Meissner Motor", which utilizes the repulsive force caused by the Meissner effect, which appears below Tc and disappears above that. This paper discribes the influence of the temperature changes and the motor structure on the motor output.

MF-14 FINITE ELEMENT MODELLING OF ELECTROMAGNETIC SHIELDS IN SUPERCONDUCTING AC GENERATOR, S. Hahn, G. Cha, D. Han, H. Sin, S. Hahn, B. Lee, Y. Won, Seoul National University, Seoul, Korea

Double-shielded single-rotor superconducting AC generator(SCG) is the most popular type among various SCG reported yet. The shield system must ensure that heat losses by the flux variation of the superconducting field winding do not drive the superconducting into nomal state. Then exact field analysis is required for the design of shield system in views of mechanical and thermal characteristics as well as shielding characteristics. For analysis of shield system during the transient state, equivalent circuit modelling based on Park's equation and frequency domain analysis have been used. Solutions obtained from the above methods give only gloval effects of the shield system. This paper deals with the finite element modelling of the shield system from which more accurate and local behaviour can be obtained. A 2 GVA SCG is simulated in the one machine-infinite bus power system. Three-line short, line-to-line short and one line to ground fault are considered to show the transient characteristics of the shield system. At each case, induced current distribution, electromagnetic force and temperature rise of the shield system are analyzed. Field and current variations of the superconducting field winding is also computed. Computing results also show effects of shield thickness and conductivity on magnetic field penentration from the armature winding into superconducting field winding.

MF-15 CALCULATION OF MAGNETIC FIELD CAUSED BY ARMATURE WINDING OF SUPERCONDUCTING GENERATOR

Kiyoshi Yamaguchi, Naoki Maki, *Hitachi Research Laboratory, Hitachi Ltd.* -Superconducting generator has a air-gap armature winding which is different from conventional generator's. Superconducting generator also has a cylindrical magnetic shield which is made of iron. The straight section of the winding locates just inside the magnetic shield and the end section is outside of the shield. Particularly, in the end section of the winding, magnetic field has three dimensional distribution. To calculate accurate synchronous reactance and leakage reactance, magnetic field and magnetic flux-turn must be calculated precisely. The end section of the winding has a conical shape and conductor bars have complex disposition. We calculated the whole magnetic flux distribution by TOSCA[1],[2]. We modeled end section of the winding as a chain of rectangular cross section bars which form a geodetic line on a cone surface.

[1] TOSCA Reference Manual, VECTER FIELDS LTD, 24 , BANKSIDE, KINGTON, OXFORD OX5 1JE, ENGLAND, 1988
[2] J. SIMKIN AND C.W.TROWBRIDGE, "THREE DIMENSIONAL NONLINER ELECTROMAGNETIC FIELD COMPUTAIONS USING SCALAR POTENTIALS", PROCEEDINGS OF THE IEE, VOL127, No.6 1980

MF-16 THERMO-ELECTROMAGNETIC STABILITY OF ULTRAFINE MULTIFILAMENTARY SUPERCONDUCTING CABLES FOR INDUSTRIAL FREQUENCY USE. A. Guéraud, J.P. Tavergnier, A. Février, Laboratoires de Marcoussis, 91460 Marcoussis, Y. Laumond, A. Lacaze, Alsthom - DEA, 90018 Belfort, B. Dalle, A. Ansart, EDF - DER, 92141 Clamart.(FRANCE).

The development from 1983 onwards of Nb-Ti ultrafine multifilamentary wires for 50-60 Hz applications has opened up many interesting perspectives in electrotechnology. The AC losses have been greatly reduced due to decreasing the filament diameter to values of 0,1 to 0,2 µm and by using a highly resistive CuNi matrix with a 30% nickel content. The low thermal conductivity and specific heat of this CuNi matrix and the very high critical current densities induce a very accute problem of thermoelectromagnetic stability. As the electromagnétic diffusivity is much higher than the thermal diffusivity, the stability is governed by an adiabatic criterion. The last experiments about various coils and different assembly configurations of industrial cables give us a large panel of results which permit us to check the validity of the theoretical calculations.

MF-17 INDUSTRIAL PERFORMANCES OF SUPERCONDUCTING CABLES FOR 50-60 Hz APPLICATIONS (*). A. Guéraud J.P. Tavergnier, A. Février, Laboratoires de Marcoussis, 91460 Marcoussis , Y. Laumond, A. Lacaze, P. Bonnet, Alsthom - DEA, 90018 Belfort (FRANCE).

Multifilamentary superconducting wires with a greatly reduced level of losses have been produced with length of several tens of kilometers. In spite of the reduction of the filament diameter, proximity effects are avoided and we take advantage to the maximum of the reversible motion of the flux lines, so that the hysteretic losses are lower. The reduction of losses due to induced currents can be obtained thanks to a twist pitch as short as possible. These concepts lead us to realize, first at a small scale, then at an industrial scale, conductors comprising filaments of Nb-Ti with a diameter of 0,1 to 0,2 µm and a highly resistive CuNi matrix. The twist pitch of these filaments is four times the diameter of the conductor. Magnetization curves show the reversible motion of the flux lines. Some coils have been tested at the frequency of 50 Hz and have very reduced losses. We obtain thus 44 kW/m^3 with an induction of 1 T and an overall current density of 1166 A/mm^2.

(*)This work has been partly funded by Electricité de France.

MF-18 INFLUENCE OF THERMOMECHANICAL TREATMENT SCHEDULES OF CRITICAL CURRENT DENSITY AND STRUCTURE OF NIOBIUM-TITANIUM BASE SUPERCONDUCTING ALLOYS, G.K.Zelenskiy, A.V.Arsent'ev, A.P.Golub', B.V.Nikulenkov, A.D.Nikulin, V.Ya.Fil'kin (A.A.Bochvar's All Union Scientific Research Institute of Inorganic Materials, Moscow, USSR). V.S.Titov, P.P.Pashkov (All Union Scientific Research Institute of Electromechanics, Moscow, USSR). V.A.Vasil'ev, A.I.Nikulin (Institute of High Energy Physics, Serpukhov, USSR).

The critical current density and the structure of specimens from superconducting HT-50 and H-55 alloy wires as determined in stages are presented. The alloys were produced without and with four intermediate anneals. If the first intermediate anneal effects a more than an order of magnitude increase of j_c, the subsequent anneals lower j_c and reduce the density of α -phase precipitates and increase their sizes. With an increase of the number of thermomechanical treatment cycles a monotonous growth of j_c is noted for both annealed and deformed specimens. A sharp increase of j_c to 3.2×10^5 A/cm^2 and 3.9×10^5 A/cm^2 as induced by deformation after the last anneal is observed in the field of 5 T for HT-50 and HT-55 alloys, respectively. Specimens not subjected to intermediate anneals show a monotonous grow of j_c with its relatively low absolute value.

MF-19 DEVELOPMENT OF KA-CLASS SUPERCONDUCTING CABLES FOR AC USE(I)-DESIGN AND FABRICATION, T.Hamajima, M.Shimada, M.Ono, M.Yamaguchi, D.Itoh and T.Fujioka, TOSHIBA CORPORATION, Yokohama, Japan.
K.Funaki, K.Tazaki, N.Iwakuma, M.Takeo and K.Yamafuji, Kyushu University, Fukuoka, Japan,
T.Kumano and E.Suzuki, Showa Electric Wire & Cable Co.Ltd., Kawasaki, Japan

We have been developing large current AC superconductors for the secondary winding of a superconducting transformer. AC superconductors have to meet the contradicting requirements of superconducting stability, mechanical loss as well as low loss at the operation of 50 or 60Hz frequencies. A more than 20,000 NbTi filaments strand was processed to 0.153mm to produce 0.57um filaments in order to reduce the hysteresis loss. The low coupling loss was achieved with the matrix composed of CuNi and Cu, whose ratio to NbTi, 2.16 and 0.16, respectively. The first-level sub-cable was assembled with 7 composites, and the second-level sub-cable with 6 first subcables wound around a stainless steel coated with Formver. The final cable conductor was made of 12 second subcables with a mandrel of stainless steel or FRP. The final conductors were compressed on four sides with Turks head to make them rigid. The relation between the DC critical current and the deformation due to the compression was studied. The critical current decreased with the compression up to about 20%, and with more compression the composite started to break. FRP material was used for a coil bobbin to reduce the eddy current loss. The bobbin was machined to provide the axial cooling channels and spiral grooves in which conductors were tightly fixed. 10 turns of the conductor were wound in one layer to form the coil of 100mm in diameter and 160mm in height. This paper describes the design of the coil and DC operation results.

MF-20 DEVELOPMENT OF kA-CLASS SUPERCONDUCTING CABLES FOR AC USE (II) - ELECTROMAGNETIC PROPERTIES, K. Funaki, K. Tasaki, M. Iwakuma, M. Takeo, K. Yamafuji, M. Ono,* M. Shimada,* K. Hamashima,* M. Yamaguchi,* D. Itoh,* T. Fujioka,* T. Kumano+ and H. Suzuki+
Faculty of Engineering, Kyushu University, Fukuoka, Japan
*Toshiba Corporation, Yokohama, Japan
+Showa Electric Wire & Cable Co., Ltd., Kawasaki, Japan

Large-current-capacity superconducting cables for AC use have been successfully fabricated and tested with regard to electromagnetic properties, stability and quench behaviors. The final cables are the compacted flat conductors made by means of triply twisting superconducting composites with NbTi filaments of 0.57 µm in diameter. Design and specifications of the cable will be minutely presented in another paper.

A superconducting transformer was constructed for test operations of the large-current-capacity cables which were mounted as the secondary winding. The secondary winding was a 10-turn coil wound on a FRP former with axial cooling channels, and the terminals of the coil was shorted by the same cable. The leakage reactance is 0.67 Ω and the ratio of the primary current to the secondary one is 17.4. The primary coil is excited up to 198 A (r.m.s.) separately. The secondary current attains to 2200 A (r.m.s.).

AC losses are evaluated by collecting helium vapor generated by the secondary winding. Stability and quench behavior are also studied by local heating of the cables.

MF-21 HIGH-FIELD SUPERCONDUCTING PROPERTIES OF 16 T CLASS $(Nb,Ti)_3Sn$ CONDUCTOR BY THE TUBE METHOD, K. Inoue, T. Takeuchi, K. Itoh, S. Murase*, H. Shiraki*, S. Nakayama*, T. Fujioka*, Y. Sumiyoshi*, and T. Hamajima*.
National Research Institute for Metals, Ibaraki, Japan,
Toshiba Corporation*, Kawasaki, Japan

Titanium doped Nb_3Sn ($(Nb,Ti)_3Sn$) conductor processed by the tube method has been developed. The Nb tube method has many advantages; (1) no intermediate annealings, (2) high Sn content and (3) no additional diffusion barriers. The fabrication process is shown as follows. The single wire consists of a Nb-1%Ti tube with copper sheathed Sn core inside and copper outside. For fabricating multifilamentary conductors, single core wires are bundled together, co-reduced to final sizes without any heattreatment and finally submitted to a reaction to form the $(Nb,Ti)_3Sn$ layer.

We have studied high-field performance around 16 T for high Sn content (50 % Sn) conductor which has been recently developed for high-field use. Critical current density (Jc) and bending strain dependency of Jc were examined in the magnetic field from 13 to 16 T for sample conductors with various aspect ratios, 1.0, 1.3 and 2.0. Obtained results are as follows ; (1) Jc of 500 A/mm^2 A at 16 T was obtained for aspect ratio 1.0 and for zero bending strain. (2) Jc decreased as aspect ratio and bending strain increase, but field dependency of Jc such as Jc(at 16 T)/Jc(at 13 T), independent of aspect ratio and of bending strain, was not changed. (3) Jc decreace of 8 % and of 20 % was observed for aspect ratio of 1.3 and of 2.0, respectively. (4) Jc decreace was less than 10 % within 0.4 % bending strain.

MF-22 PARAMETERS RELEVANT TO "N"-VALUE IN Nb3Sn SUPERCONDUCTING WIRES,* K. Katagiri, M. Fukumoto, K.Saito, M. Ohgami, T. Okada, †A. Nagata,†K. Noto,†K. Watanabe, +H. Yoshida,+H. Kodaka, ISIR, Osaka University, Ibaraki, Osaka, †IMR, Tohoku University, Sendai, Miyagi,†RRI, Kyoto University, Kumatori, Osaka, Japan -- Parameters which influence on the quality factor "n" value describing the sharpness of the take-off of V vs. I curves in both bronze processed multifilamentary and in situ processed Nb3Sn superconducting wires were studied. Parameters covered are 1)strain, cyclic strain, 2)wire construction, 3)stabilizer, and 4)neutron irradiation. The value "n" changed with strain in almost the same manner as the critical current Ic. The intrinsic irreversible strain limit as determined by "n", however, was smaller than that determined by Ic in bronze processed wires whereas coincidence between both was good in the case of in situ processed ones. The "n" increased and then decreased with neutron fluence corresponding to the changes in Ic and upper critical field.

*Research partly sponsored by Grant in Aid for Scientific Research No. 63050006, Ministry of Education, Science and Culture, Japan.

MF-23 THE EFFECT OF MANGANESE ADDITION TO MULTIFILAMENTARY Nb_3Sn SUPERCONDUCTING WIRE, M. Sugimoto, N. Sadakata, M. Tange and O. Kohno, Tokyo Laboratory, Fujikura Ltd., Tokyo 135, Japan.

The application of multifilamentary superconducting wires and conductors in 50/60 Hz a.c. use is now predicted to be possible due to the recent advances in the technology of ultra-fine multifilamentary wire. Much effort has been dedicated to Nb-Ti composites wires, meanwhile development of efficient Nb_3Sn supeconductors are eagerly expected. In composite wires with very fine filaments, the proximity effect among neighboring filaments decreases the transverse resistivity and results the effective filament diameter to be much larger. The reduction of proximity effect could be obtained by widening filament spacing or by reducing the penetration in the normal matrix around the superconducting filaments. Addition of other element, for instance, manganese, is one of the candidate to realize it, although, the additive would diffuse in Nb_3Sn layer during the final heat treatment. The effect of the additive on the superconducting properties such as Tc and Jc are not clear to date despite it is indispensable for future application. In this paper, we study the influence of manganese addition on both superconducting and electromagnetic properties to the wires containing several thousand of Nb_3Sn fine filaments. In order to investigate lowering the a.c. losses in the in multi-filamentary Nb_3Sn wires, the reduction of the filament diameter and the reduction of the proximity effect by manganese addition will be also discussed.

MF-24 DEVELOPMENT OF Nb_3Al MULTIFILAMENTARY SUPERCONDUCTORS, T.Takeuchi, M.Kosuge, Y.Iijima and K.Inoue, National Research Institute for Metals, Tsukuba 305, Japan, and K.Watanabe, Tohoku University, Sendai 980, Japan

Recently, we have developed a new Nb tube method for fabricating continuous ultrafine Nb_3Al multifilamentary superconductors, where Al-based alloys are used as core materials to improve the cold-workability of the Nb/Al multifilamentary composite, leading to ultrafine Al filaments(filament number: 121 x 121 x 121, filament diameter: less than 100 nm) embedded in the Nb matrix. In this process, a bundle of 121 composites was three times packed to a Nb tube to get large reduction in area of Al core. The short inter-diffusion distance between Nb and Al permits the submicron Nb_3Al filament to form even at reaction temperatures below 850 °C, resulting to excellent superconducting properties. The highest J_c of 1.5 10^9 A/m^2 at 10 T is obtained by the single-stage reaction at 850°C for the Nb/Al-5at%Mg composite with 90 nmϕ Al cores. The present Nb_3Al is also interesting as a low AC loss superconductor, because Nb tubes used at the bundling process can be easily replaced with high resistive materials such as Cu-Mn, Nb-V and Nb-Ta which reduce the electrical coupling between filaments. However, the H_{c2} of the present Nb_3Al reacted by the single-stage reaction below 850°C is lower than 21.5 T, so that J_c falls down rapidly when the magnetic field is above 15 T. To improve the H_{c2}, we tried both the Ge addition to the Al core and the two-stage reaction consisting of the first reaction above 1000°C and the second reaction at 700°C. The highest T_c of 17.2 K, H_{c2}(4.2K) of 24.4 T and J_c(4.2K,20T) of 5 x 10^7 A/m^2 are obtained at least hitherto, for the Nb/Al-lat%Cu-lat%Ge composite wire with 90 nmϕ Al cores.

MF-25 STRAIN EFFECTS AND PINNING MECHANISM IN Nb_3Al MULTI-FILAMENTARY SUPERCONDUCTORS, T. Kuroda, H. Wada, M. Yuyama and K. Itoh, National Research Institute for Metals, Ibaraki, Japan. Nb_3Al multifilamentary conductors which potentially have high field properties superior to practical Nb_3Sn and V_3Ga conductors were examined in terms of their sensitivity to strain. The Nb_3Al multifilamentary conductors used were fabricated through an improved composite-diffusion process[1] recently developed at NRIM; each composite conductor was composed of a Nb matrix containing more than a million of ultrafine Al alloy cores. Although the additives to the core were not detected in the Nb_3Al layer,substantial effects of the composite core composition were observed on both critical temperatures, Tc, and critical currents, Ic. ON the other hand, neither Tc nor Ic versus strain behavior was found to be affected by the core composition. These results were discussed in terms of so-called strain scaling law and pinning behavior, to see if the present Nb_3Al conductors can well be used in large scale applications where superconducting materials are subjected to strong Lorentz forces.

1) K. Inoue et al: Appl. Phys. Lett., 52(1988)1724

MF-26 MAGNETIZATION OF COMPOSITE-DIFFUSION PROCESSED Nb_3Al SUPERCONDUCTORS CONTAINING ULTRAFINE FILAMENTS, K. Itoh, M. Yuyama, T. Kuroda, T. Takeuchi, M. Kosuge and H. Wada, National Research Institute for Metals, Ibaraki, Japan. Nb_3Al multifilamentary conductors were fabricated by an improved composite-diffusion process[1] recently developed at NRIM; each composite conductor consisted of a Nb matrix and about 1.7 million of Al-lat%Cu-lat%Ge alloy cores of submicron in diameters. Magnetization measurements were performed using a vibrating sample magnetometer in fields from 0 to 8 tesla at 4.2 K, and effective superconducting filament diameters in fields were estimated. Critical current measurements and scanning electron microscopy on the cross sections of sample conductors were also carried out. The effective diameters for ultrafine filaments were found to be about 5 μm, showing that there existed electrical contacts between filaments which needed to be avoided in practical conductors for ac use.

1) K. Inoue et al: Appl. Phys. Lett., 52(1988)1724

MF-27 Nb TUBE PROCESSED MULTIFILAMENTARY Nb_3Al WIRES IN COMPARISON WITH POWDER METALLURGY PROCESS, K. Watanabe, K. Noto*, Y. Kamisada**, E. Suzuki**, and Y. Muto, Institute for Materials Research, Tohoku University, Sendai 980, Japan. * Department of Electrical Engineering, Iwate University, Morioka 020, Japan ** Showa Electrical Cable and Wire Corp., Kawasaki 210, Japan.

Various manufacturing processes of Nb_3Al superconducting wires have been investigated. Recently, Nb tube processed multifilamentary Nb_3Al wires were developed, and this new method gave impact against realization of practical Nb_3Al wires. However, a short interdiffusion distance of Nb and Al is required for formation of Nb_3Al by a solid phase reaction. In fact, a very large areal reduction ratio R of 10^8~10^{10} is performed for the Nb tube method, and composite wires with Al core diameters below 0.1 μm are fabricated. We have investigated the formation mechanism of Nb_3Al in both powder metallurgy and multilayer process. We pointed out that the extremely thin Nb thickness is not needed, and that the diffusion process is strictly related to the areal reduction ratio R. Now, we fabricated Nb-Al wires with large Al cores which correspond to the Nb thickness of R≈10^4 in powder metallurgy process. Superconducting properties for Nb tube processed multifilamentary Nb_3Al with relatively large Al cores of 0.6 μm were examined. Interesting results will be discussed in comparison with powder metallurgy process..

MF-28 Nb_3Al SUPERCONDUCTING WIRES FABRICATED BY THE CLAD-CHIP EXTRUSION METHOD, S. Saito, K. Ikeda, Institute for Materials Research, Tohoku University, Japan, S. Ikeda, Department of Materials Science and Engineering, Miyagi National College of Technology, Japan, A. Nagata, Department of Metallic Materials for Engineering, Akita University, Japan, K. Noto, Department of Electrical Engineering, Iwate University, Japan

We developed a new process for fabricating the Nb-Al composite wire which was named as the clad-chip extrusion (CCE) method. In this method, thin clad chips of Nb sandwitched by Al were used as a starting material. The use of thin clad chips intends to achieve the improvement of workability, large areal contact between Nb and Al layers and relatively low reduction ratio. Another distinctive feature of the CCE Method is to arrange randomly packed clad chips to the longitudinal direction by the shear deformation in the extrusion process. Heat treatments at temperatures of 1273~1373K and subsequently at 998~1023K for 96 hours gave high critical current densities. Best superconducting properties were obtained for the samples with an areal reduction ratio of 3×10^6 and heat-treated at 1373K for 60 seconds + 998K for 96 hours, indicating J_c of 1×10^8 A/m^2 at 4.2K and 18.8T, T_c of 17K and B_{c2}* of 23.2T at 4.2K. There was no evidence of saturation of J_c even at the maximum reduction ratio achieved in this experiments. Although required areal reductions are larger by one order in comparison with the P/M process, it is possible to decrease areal reductions by employing thinner clad chips. The effect of additive elements on superconducting properties will be also presented in this paper.

MF-29 FABRICATION OF SUPERCONDUCTING TAPES BY YAG-LASER IRRADIATION, H. Wada, M. Yuyama, T. Kuroda, K. Itoh, Y. Nimura*, A. Shimomura* and K. Shinohara*, National Research Institute for Metals, Ibaraki, Japan and * Nihon Koshuha Co Ltd., Yokohama , Japan. A YAG-laser based apparatus equipped with two reaction chambers providing various atmospheres has been developed for fabricating superconducting tapes . One of the chambers contains a stage movable to X and Y directions and attachable with sample tapes up to 5 cm long, while the other has a rotating wheel on the circumference of which a 1 m long sample tape can be mounted. For fabricating a NbC or a NbNC superconducting tape a carbon layer typically 5 μm thick was magnetron-sputtered on a niobium substrate. Such a composite tape was then mounted in the reaction chamber, and irradiated at a laser beam energy up to 100 W and at a moving speed between 0.025 to 250 mm/s in an argon or a nitrogen atmosphere. In the case of Nb_3Al a niobium substrate was first coated with an aluminum layer typically 5 μm thick and, then, with a carbon layer 2 μm thick, both by magnetron-sputtering. The composite tape was subsequently irradiated in an argon atmosphere. Superconducting critical temperatures so far obtained in the present study are around 9.2 K for NbC, 14.5 K for NbNC and 15.2 K for Nb_3Al, depending on the fabrication conditions.

MF-30 MAGNETIC CONDITIONING FOR FLUX JUMP INSTABILITIES IN SUPERCONDUCTING Nb_3Sn TAPE MAGNET, H. Kobayashi, T. Tada, M. Uchida and Y. Toyoda, Atomic Energy Research Institute, Nihon University, Tokyo, Japan

Magnetic instabilities in a superconducting Nb_3Sn tape magnet were classified into two types i.e. minor flux-jump and major flux-jump: the formar occurs successively during sweep until the quench is triggered by the latter. Minor flux-jumps are observed on the major loop of magnetization. When the superconducting Nb_3Sn tape magnet was disturbed by cyclic magnetic pulses with moderate frequency produced by another small magnet placed inside the bore, minor flux-jumps disappeared after the application of each pulse. The major flux-jumps seem to be triggered by the minor flux-jump on condition that the maximum radial component of magnetic induction B_{max} equals to the critical magnetic induction B_{fj} for major flux-jump. Therefore the collapse of magnetization prior to the occurrence of the minor flux-jump by artificial disturbances may enhance the stabilization of the magnet, so that quench currents Iq are increased. This way of magnetic conditioning has been demonstrated with the superconducting Nb_3Sn tape magnet in He I(4.2 K) and He II(1.9 K), and resulted in increases in quench currents by 30% and 70% of the natural quench current level at 4.2 K at a given sweep rate, respectively.

AUG. 31 (Thr) Session MG (oral) 16:00-17:40

FUSION MAGNETS-2
Room A

Chairman: D. P. Ivanov
Kurchatov

Cochairman: O. Tsukamoto
Yokohama Nat. Univ.

16:00 MG-01 EVOLUTIONS OF THE DEMO. POLOIDAL COIL PROGRAM, H. Tsuji, E. Tada, K. Okuno, T. Ando, T. Hiyama, Y. Takahashi, M. Nishi, K. Yoshida, Y. Ohkawa, K. Koizumi, H. Nakajima, T. Kato, K. Kawano, T. Isono, H. Yamamura, M. Satoh, J. Yoshida, N. Itoh, M. Oshikiri, Y. Kurosawa, H. Nisugi and Y. Matsuzaki, H. Shirakata, S. Shimamoto, Japan Atomic Energy Research Institute, Ibaraki 311-01 Japan

Demo. Poloidal Coil (DPC) Program has been conducted by Japan Atomic Energy Research Institute (JAERI) since 1985, aiming to demonstrate and achieve a series of technologies to construct the superconducting poloidal coils of the Fusion Experimental Reactor (FER) as the next large tokamak machine in Japan.
In the DPC program, the following key technologies have been developed:
a) test coils : DPC-U1, DPC-U2 (NbTi), DPC-EX, DPC-TJ (Nb_3Sn)
b) cryogenic system : circulation with 4-K He pump (500 g/s)
c) power system : supply and control system (58 kA, 5 kV)
DPC-U1 and U2 are 30-kA, 7-T, 7-T/s pulsed coils with the stored energy of 30 MJ. This energy is increased to 40 MJ by adding DPC-EX, which is a 10-kA, 7-T, 7-T/s pulsed coil. The conductor of DPC-EX has a capability to operate at 10 T. DPC-TJ, which is a DC coil to test high current density up to 40 A/mm^2, has been developed under a cooperative R&D with Toshiba Co. Ltd.
In 1988, construction of the cryogenic system and power supply and control system were completed. Its helium circulation pump was operated reliably up to 500-g/s at 4 K extending the specified capacity of 350 g/s. Supply current was also controlled to increase up to 40.5 kA in one second. From 1989, testing of the coils are started and developed key technologies will be demonstarted. This paper describes the role and perspectives of DPC program in a systematic technology development for FER based on the latest achievements by the coils and test facilities.

16:20 MG-02 THE US-DPC TEST COIL AND ADVANCED CONDUCTOR DEVELOPMENT IN PULSED MAGNETS. M.O.Hoenig, M.M.Steeves, M.Takayasu, T. Painter, I.S.Hwang, M.M.Morra and R.G.Ballinger, MIT, Cambridge, MA 02139 — In the design of the US-DPC we have attempted to utilize the most advanced pulsed conductor technology available at the time of design. The test coil , currently in fabrication, is scheduled for testing in early 1990 in the Demonstration Poloidal Coil Facility (DPCF), at JAERI, Japan. Major objectives for the US-DPC test include AC operation at ramp rates exceeding 5 T/s, with peak flux densities of 9 to 10 T and a peak operating current of 30 kA. The test coil's cable-in-conduit conductor (CICC) has been double jacketed in order to enhance cooling . At high ramp rates AC loss is expected to be significant due to the use of commercial superconductor. A major feature of the US-DPC is its Incoloy 908 conduit, which was specifically developed for its CICC, and which is the coils primary means of axial as well as radial structural support. In terms of advanced CICC conductor development, we are looking forward to the use of two major advancements in base technology: (i) the use of commercially available Nb_3Sn wire with 200 to 300 A/mm^2 (non-Cu) current density at 17.5 T and (ii) a 20 to 25 % increase in Incoloy 908 Yield Strength . These, more than any other factors, should facilitate the development of 15 to 20 T ramped magnets with peak overall current densities close to 40 A/mm^2. The paper describes plans for the testing of 45 strand CICCs at 17 to 18 teslas, measurement of J_c degradation due to transverse cable stresses, extensive, small scale fatigue testing, and the possible design of a new US-DPC insert into a 12.5 to 15 T upgraded DPCF facility.

16:40 MG-03 THE FIRST EXPERIMENT OF THE 30-kA, Nb-Ti DEMO POLOIDAL COILS (DPC-U1 AND -U2), K. Okuno, H. Tsuji, Y. Takahashi, H. Nakajima, K. Kawano, T. Ando, T. Hiyama, M. Nishi, E. Tada, K. Yoshida, K. Koizumi, T. Kato, T. Isono, H. Yamamura, M. Satoh, J. Yoshida, N. Itoh, M. Oshikiri, H. Nisugi, M. Konno, E. Kawagoe, Y. Kamiyauchi, M. Hasegawa, Y. Matsuzaki, T. Satou*, T. Ichihara*, and S. Shimamoto, Japan Atomic Energy Research Institute, Ibaraki, 311-01, Japan, *Mitsubishi Electric Corp.

The first operation of the Demo Poloidal Coils, DPC-U1 and -U2 was successfully performed with the JT-60 pulsed power supply as well as DC power supply. Coil fabrication was completed in January, 1989, and installation work started in the Demo Poloidal Coil Facility (DPCF) at Japan Atomic Energy Research Institute (JAERI). The coils have 30-kA Nb-Ti cable-in-conduit conductor and their windings have 1-m inner and 2-m outer diameters. The coils were arranged in coaxial configuration with a gap of about 300 mm. Cooldown of the coils started after the final check in 5-m vacuum tank, and a total weight of about 22 tons was cooled to cryogenic condition in 123 hours without causing any damages. In the first step of experiments, the coils were charged individually to their rated current of 30 kA by DC power supply and generated the maximum magnetic field of 5.2 T. Stored energy in the individual charge was 11 MJ. During the charge both coils were cooled by 4.2-K, 0.6-MPa supercritical helium with a mass flow rate of 150 g/s each coil. In the second step, one of the coils was connected to the JT-60 power supply whose capacity was ±5 kV and ±58 kA, and pulse operation was performed. The coil was charged to the rated current in 0.75 s and produced a pulsed field of 7 T/s, and after 0.5 s holding of the current, the coil was ramped down in 0.75 s. Through these operations, the coils demonstrated an excellent low ac loss performance as expected from their design.

17:00 MG-04 PROGRESS IN THE DEVELOPMENT OF A 40 KA SUPERCONDUCTOR FOR THE NET CENTRAL SOLENOID, J.V. Minervini, N. Mitchell, R. Poehlchen, M. Ricci, E. Salpietro, The NET-Team, Garching bei Muenchen, FRG, A. Torossian, CEA-CEN de Cadarache, France, P.Bruzzone, J. Rauch, ABB Zuerich, Switzerland, P. Blasio, S. Ceresara, Europa Metalli/LMI Florence, Italy.

A 40 KA wind and react, Nb_3Sn superconductor is being developed in two versions for the central solenoid of NET. The conductor must operate in pulsed mode between ± 12.5T. One type under development by ABB/Zuerich uses a multistrand Nb_3Sn cable enclosed in two U-shaped steel jacket halves by simultaneous laser welding of the two longitudinal seams. A second type of conductor is being developed by Europa Metalli/LMI, Florence. In this design a Rutherford cable is made by cabling 8 sub-elements composed of multistrand Nb_3Sn sub-cable twisted around individual cooling tubes. The cable is put in the steel jacket by pulling it through a complete length of jacket formed by butt welding extruded full cross-sections. This paper reports the status of the project including the cable development, strand coating, jacket forming and welding, and gives a summary of results measured on the conductor components to understand and qualify the final conductor.

17:20 MG-05 DEVELOPMENTS OF THE PROTO-TYPE CONDUCTORS AND DESIGN OF THE TEST COIL FOR THE FUSION EXPERIMENTAL REACTOR, K. Yoshida, M. F. Nishi, Y. Takahashi, H. Tsuji, K. Koizumi, K. Okuno, Y. Wachi, I. Itoh and T. Ando, Japan Atomic Energy Research Institute - The proto-type conductors of the toroidal coil are developing for the fusion experimental reactor. Specifications of the conductor are expected as follows:

(1) conductor type : forced flow,
(2) operation current : 30 kA at 12 T and 4.2 K,
(3) critical current : 60 kA at 12 T and 4.2 K,
(4) current density of winding : 30 - 40 A/mm^2,
(5) applied pulsed field : 1 T/s - 10 s, 10 T/s - 100 ms,
(6) inlet helium : 4.2 K, 4 - 10 bar.

Three type conductors were selected for conductor development program as follows:

(a) TMC-FF type : hollow cooled type and Test Module Coil Nb_3Sn conductor technology,
(b) Preformed armor type : semi-react-wind technique, cable-in-conduit and double conduit,
(c) Advanced disk type : semi-react-wind technique and disk reinforced.

The trial manufacturing were progressed to solve their design concepts. The test coil was designed to evaluate the mechanical and electrical properties, stability, and safety. Two LCT coils, the LCT backup coils and thier coil configuration were also designed to supply background field in the test coil. This paper describes trial manufacturing results of three type candidate conductor and design of the test coil.

AUG. 31 (Thr) Session MH (oral) 16:00-17:40

MAGNET TECHNOLOGY FOR RESEARCHES-2
Room B

Chairman: Y. Iwasa, MIT

Cochairman: T. Ishigohka, Seikei Univ.

16:00 MH-01 SUPERCONDUCTING MAGNET FOR ENERGY DEVICES, G.I.Agapov, V.R.Karasik, O.A.Kleshnina, A.A.Konjukhov, V.A.Malginov, V.V.Matokhin, M.V.Sidorov, V.S.Vysotsky, P.N.Lebedev Physical Institute of the AS USSR , Moscow

On the base of long time researches in Lebedev Institute the physical principles and technology of superconducting magnets with high current density and persistent mode were developed. There are a computer simulation programs for calculating of the stresses in windings and calculating method for coil protection schemes by subdivision with shunting low ohms resistors. The calculating methods and technology of persistent switches were also developed. Largest of desined magnets were solenoids with inner diameter - 760 mm, outer - 940 mm, height - 180 mm, maximal field on winding - 7,4 T . Coils were wound by multifilament Nb-Ti/Cu wire with 1 mm diameter. Magnets were tenthly quenched at storage energy level up to 2,5 MJ and overall current density $1,2 \cdot 10^8$ A/m^2 without any change for the worse of parameters. They carefully worked at persistent mode. Similar magnets can used for unipolar mashines, magnetic levitation etc.

16:20 MH-02 FABRICATION AND TESTING OF THE CPQ COIL.* S.S. Shen, R.E. Patrick, J.R. Miller, M.R. Chaplin, J.R. Heim, J.A. Kerns, D.S. Slack, and L.T. Summers, Lawrence Livermore National Laboratory, Livermore, CA, USA

The Conductor Performance Qualification (CPQ) coil intends to demonstrate the acceptable performance of cable-in-conduit conductors (CICC) produced in large quantities from Ti-modified, internal-tin process, MF-Nb_3Sn. In addition, the fabrication and tests of the coil will provide much needed engineering data on crucial materials and processes for large applications, such as the ITER (International Thermonuclear Experimental Reactor) magnet systems.[1] The CPQ coil is designed to operate at a maximum field of 15 T as an insert to the High-Field Test Facility Solenoid at LLNL. Major design parameters are: inside diameter, 150 mm; outside diameter, 300 mm; coil height, 420 mm; coil current, 5000 A; conductor grading, 4; current density at B_{max}, 40 A/mm^2 at 15 T; forced-flow cooling, 5 g/s at 4.2 K. Techniques appropriate for the insulate-wind-react-impregnate method of coil construction using CICCs are developed and demonstrated. A unique feature of this coil design is the employment of a novel ripple-current heating scheme to inject heat at specific levels appropriate for a close simulation of the ITER environment of ac and nuclear heat loads. Up to 5 kW of heating power can be simulated within the coil winding, allowing the effects of such heating on the coil performance to be investigated. This paper is a summary report on the coil construction and its preliminary test results. Reference 1: C. D. Henning and J. R. Miller, *Design Considerations for ITER Magnet Systems*, 8th Topical Meeting on Technology of Fusion Energy, 1988.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

16:40 MH-03 PROGRESS REPORT OF THE HIGH FIELD SUPERCONDUCTING FACILITY AT LASA LABORATORY, E. Acerbi, G. Baccaglioni, C. Barrilà, L. Rossi, G. Varieschi.

A 19 Tesla facility for critical current and basic material properties measurements is under construction at LASA (Laboratorio Acceleratori e Superconduttività Applicata) in Milan. In this paper, after a brief description of the external solenoid (8 T, coil diameter 630 mm, free bore at 300 K = 550 mm) now under construction, we present the design and the stability studies of the first internal solenoid wich will increase the field up to 15 Tesla in a 240 mm bore at 4 K. The cable is a commercial $(NbTa)_3Sn$ Rutherford type with some pure copper stabilizing strands to be used with "wind & react" technique. The cable quality has been carefully investigated by measuring the mechanical properties and the electrical and thermal conductivities and by performing preliminary test of critical current on short reacted samples.

17:00 MH-04 DESIGN OF 20 T CLASS SUPERCONDUCTING MAGNET WITH LARGE BORE, T. Kiyoshi, K. Inoue, K. Itoh, T. Takeuchi, H. Wada, H. Maeda, K. Nii, K. Kuroishi*, F. Suzuki*, T. Takizawa* and N. Tada*, National Research Institute for Metals, Ibaraki, Japan, Hitachi, Ltd.*, Ibaraki, Japan

As one of the major technological challenges in the Multi-Core Research Project on Superconductivity promoted by the Science and Technology Agency, Government of Japan, a 20 T class superconducting magnet system is now under construction at the National Research Institute for Metals. This magnet system is designed to meet two contradicting requirements; a large bore diameter and generation of high magnetic fields. The magnet consists of four coils including two outer coils, one middle coil and one inner coil, and should be operated at 1.8 K in saturated superfluid helium to generate its highest field. The outer coils connected in series are assumed to generate magnetic fields up to 14.8 T in a clear bore of 350 mm. The conductor for the outermost coil (the outer-2 coil) is composed of multifilamentary NbTi strands, while the outer-1 coil conductor contains multifilamentary $(Nb,Ti)_3Sn$ strands. Both conductors are cryogenically stabilized with copper and aluminum. The middle coil, using a monolithic conductor of multifilamentary $(Nb,Ti)_3Sn$, generates a magnetic field of 3.2 T. The outer and middle coils together should be able to generate a magnetic field as high as 18 T in a 160 mm diameter bore, in which the inner coil will be inserted to generate an incremental field of over 2 T. The total stored energy of this magnet system is estimated to be about 43 MJ, the greater part of which is stored in the outer coils. The outer coils are placed in an outer chamber of the cryostat and separated from the other coils. The quench of the inner or the middle coil should have no essential effect on the stability of the outer coils.

17:20 MH-05 AN APPROACH TO THE CONCEPT OF LARGE SCALE AND COMPLEX GEOMETRY SUPERCONDUCTING HELICOIDS, V.E.Keilin, I.A.Kovalev, N.F.Kopeikin, S.L.Kruglov, D.B.Pavin, Kurchatov Atomic Energy Institute, Moscow, USSR.

Previous experiments [1] demonstrated the feasibility of SC helicoids. Present investigations are aimed at clarification of specific features of helicoids compared to conventional SC windings. A relatively large helicoid was built and successfully tested. The helicoid consisted of copper rings (ID 180 mm, OD 320 mm) soft soldered one to other forming a spiral. The NbTi wires were soldered into 25 concentric grooves machined onto each ring. The current carrying capacity of the coil versus current charging rate was investigated. The heat generation in soldered joints was rather high (supposedely due to current distribution across the joint) and corresponded to 0.3 W or $6 \cdot 10^{-4}$ Ohm per joint at 7 kA and the heat removal was only through cylindrical surfaces of the coil. Nevertheless the induction of nearly 4.2 T limited with 10 kA current supply was achieved at practically suitable 6 mT/s charging rate. To reproduce high mechanical stresses typical for large windings the racetrack helicoid without any bandages was built. The internal dimension of the winding are 56 mm and 128 mm, winding thickness is 11 mm. The turnes are composed of NbTi wires soldered together with PbSn solder, which yield stress is 100...150 MPa. After several training steps the racetrack achieved its short sample current, maximum bending stress being as high as 300...400 MPa. These results give grounds to further developing of large scale and complex geometry helicoids.

1. V.E.Keilin, I.A.Kovalev, N.F.Kopeikin, S.L.Kruglov, D.B.Pavin, Paper K 1.5 presented at ICEC-12, July 12-15, 1988, Southampton, UK.

SEPT. 1 (Fri) Invited Talk Q7 9:00-10:00

9:00 PROGRESS IN RESEARCH OF HIGH TEMPERATURE SUPERCONDUCTORS AND THEIR APPLICATIONS
Hall H
Speaker: S. Tanaka, ISTEC
Chairman: K. Tachikawa, Tokai Univ.

SEPT. 1 (Fri)

10:10 CONCLUDING REMARKS
Hall H
S. Shimamoto, MT-11 Conf. Secr. General

SEPT. 1 (Fri) Session NA (oral) 10:50-12:30

MHD AND SPACE APPLICATION
Room A
Chairman: J. D. Elen, ECN
Cochairman: S. Nishijima, Osaka Univ.

10:50 NA-01 THE INFLUENCE OF THE MAGNET ON THE PERFORMANCES OF A COLD MHD DEVICE, P. Del Vecchio, G. Pasotti and G.M. Veca, IEEE Senior Member, Electrical Energy Dept., University of Rome-La Sapienza and ENEA/Frascati, Italy

With reference to a device for pumping melted metals, two configurations of superconducting magnets - a saddle coils and a racetrack coils - are analyzed. Such configurations are relative to two types of ducts, one in circular cross-section and the other in rectangular cross-section. The performances of the two pumps with the magnetic fields produced by the two coils are compared to those obtained using maps of uniform magnetic fields. For some years now a model has been perfected to valuate the performances of the D.C. MHD device taking into account the edge effects (inlet and outlet sides) and the number of electrodes but assuming a spatial uniform distribution of the magnetic flux density. In this paper the calculation of the external magnetic field is carried out using a GFUN program while the calculation of the induced reaction magnetic field is carried out using a computing code proposed by the authors based on the vector potential algorithm. The features of the pump are obtained simulating the fluid and its duct by means of an electrical equivalent lumped parameters network.

11:10 NA-02 MHD MAGNET DESIGN FOR THE J. E. CORETTE PLANT RETROFIT, H. Gurol, General Dynamics Space Systems Division, San Diego, California, U.S.A.

The purpose of this paper is to discuss the conceptual design of the superconducting magnet system for the coal-fired MHD retrofit of the Corette plant. The basic magnet requirements are driven by increased MHD system performance, and a high degree of reliability. High magnetic fields increase the net channel output from MHD systems: the peak channel field used is 4.5 T. These high magnetic fields require the use of superconducting coils to reduce operating costs. Reliability is enhanced by using a current density of about 3,000 A/cm^2, resulting in a high stability margin. The conductor concept chosen is NbTi cooled with pool-boiling 4.2 K helium. An efficient superstructure is used to carry the Lorentz forces when the coil is operating. Wherever possible, off-the-shelf components are used for power supplies, refrigerators, etc. In terms of overall size and stored energy this coil is similar to other large magnet systems that have been built and operated successfully, and hence will not require any new technology development.

* Work performed under contract to the MHD Development Corporation

11:30 NA-03 HIGH FIELD SUPERCONDUCTING MAGNET FOR A CLOSED CYCLE DISK MHD GENERATOR, T.Okamura, Y.Okuno and S.Shioda, Tokyo Institute of Technology, Tokyo, Japan

Advantages of a high magnetic field up to 10 T for a closed cycle MHD generator are discussed, and technical feasibility of its superconducting magnet is studied. A disk type generator is considered, because it has high performances for a large value of Hall parameter, which is realized when magnetic field is high. The thermal input to the MHD generator is assumed to be 1000 MW, which is a typical value for commercial generators. Helium and argon are considered as a working gas. Numerical results indicate that its performance can become extremely high for high magnetic field of 10 T. Isentropic efficiency, enthalpy extraction and output power density approach 80 %, 50 % and 1 GW/m^3, respectively which can be compared with values of 70 %, 35 %, 100 MW/m^3 for lower magnetic field in the range of 4~5 T. We can say that this is, so to say, "the second generation" of MHD power generator. The magnet is considered to be a Helmholtz-type, in which two circular coils face each other with a space left in between to accommodate the generator. As the magnetic field strength in the MHD channel increases from 6 T to 12 T, the output power density increases three times to that of its value of 6 T, whereas the stored energy of the magnet increases only by two times. This means that the ratio of the stored energy to the output power density becomes smaller as the magnetic field strength increases. The maximum magnetic field strength in the coils becomes about 20 T. One of the possible ways to reach such a high field is to cool the coils by superfluid helium and a Nb_3Sn conductor is partially employed at the location of high field. A special structure is considered to sustain a large electromagnetic force induced between the coils, and its feasibility is examined.

11:50 NA-04 SENDING PAYLOADS INTO SPACE VIA AN ELECTROMAGNETIC LAUNCHER, E.M.W.Leung, R.E.Bailey, D.D.Madura and L.R.Patterson, General Dynamics Corporation, Space Systems Division, San Diego, California, USA.

Using ElectroMagnetic Launch(EML) for delivery of payloads into space is not a new idea. Science fiction writers and scientists have suggested it as a viable concept for over sixty years. In WWII, EML was a competing design among the German military engineers in delivering explosives and bombs to enemy targets, until it was beat out by the rocketry idea as exemplified by the successful V-2 rocket. After the war, chemical rockets continued to dominate, slowly moving from military to space exploration applications. Recent interest in employing the railgun (one form of electromagnetic launcher) concept in the Kinetic Energy Weapon(KEW) system for the Strategic Defense Initiative (SDI) program has led to rapid development of different types of launcher concepts, including the coil gun, electrothermal gun, hybrid rocket gun and, of course, the classical railgun. The technology is now capable of generating hundreds of thousands of g's in acceleration and delivering small masses (0.5 - 1.0 Kg) to a maximum velocity of 6 Km/s. With recent advances in both the high and Low temperature superconductivilties, it is time to reevaluate EML as a means of delivering useful payloads into space and hence the ElectroMagnetic Launch To Space (EMLTS) concept. We have conducted a 4-month study during the second half of 1988, to explore and understand the technical challenges and barriers that have so far prevented the actual implementation of the EMLTS. This presentation will summarize some of our findings and give an assessment of the feasibility of this latest potential application of magnet technology.

12:10 NA-05 DEVELOPMENTS OF A THIN SUPERCONDUCTING SOLENOID FOR PARTICLE ASTROPHYSICS, Y.Makida, A.Yamamoto, T.Haruyama, H.Inoue, N.Kimura, H.Yamaoka, N.Minowa and Y.Doi, National Laboratory for High Energy Physics (KEK), Ibaraki, JAPAN, T.Mito, University of Kyoto, Kyoto, JAPAN

A thin superconducting solenoid is being developed in KEK for particle astrophysics and the prototype magnet for balloon experiments is under construction. It has a diameter of 1.0m, a length of 1.3m and provides a central magnetic field of 1.2 Tesla with a stored energy of 815 kJ. The wall thickness (transparency) is 0.2 radiation thickness per wall. The magnet design is based on the aluminum stabilized superconductor with a small nominal current of 520 A and on the concept of the indirect cooling (conductive cooling) without any active cooling mechanism. It enable us to optimize the magnet design in space application with minimum weight and with its reliable operation. We report on the present design, fabrications and performance of the prototype superconducting magnet. A new concept to optimize the magnet design in space application will be also discussed.

SEPT. 1 (Fri) Session NB (oral) 10:50-12:30

CONDUCTOR DEVELOPMENT AND FABRICATIONS-3
Room B

Chairman: S. S. Shen, LLNL

Cochairman: T. Yamada, Mitsubishi

10:50 NB-01 HIGH CRITICAL CURRENT DENSITIES IN FINE MULTIFILAMENTARY Nb-46.5wt%Ti COMPOSITES, K.Matsumoto and Y.Tanaka, Yokohama R&D Laboratories,The Furukawa Electric Co.,Ltd., Yokohama,Japan

Critical current densities, Jc, in NbTi multifilamentary wires have been developed by various trials of Jc optimization for high field use. The important factors which should be controlled in order to enhance Jc in the NbTi superconducting composite are both the increase of intrinsic pinning force of the NbTi alloy filaments and the keeping uniformity of filaments in the longitudinal direction of the wire during fabrication process. However it is difficult to realize these two factors simultaneously in practice, because intermetallic compounds are formed during heat treatments of the composite such as extrusion or precipitation process of α-Ti and they make a chance of sausaging in the filaments resulting in the degradation of Jc and the breakage of the wire in the extreme case. For discussing the intrinsic Jc of the fine multifilamentary wire, the effect of sausaging must be removed. The alloy rod used in this study was a high homogeneous alloy of nominal Nb-46.5wt%Ti and the final superconducting wires were made by the multi-stacking technique. The supression of the intermetallic compounds were performed with using diffusion barrier around NbTi filaments and thus the intrinsic Jc , which is not affected by the filament ununiformity, of NbTi superconducting wire with fine filaments (<10μm) was investigated. The n value of these composites are relatively high in comparison with other fine multifilamentary wires and the maximum Jc at 5T is over 3800 A/mm^2.

11:10 NB-02 DEGRADATION OF THE CRITICAL CURRENT OF MULTIFILAMENTARY Nb_3Sn WIRES UNDER TRANSVERSE MECHANICAL LOAD, H. Boschman, P. Fornerod, H.H.J. ten Kate and L.J.M. van de Klundert, University of Twente, Applied Superconductivity Centre, Enschede, The Netherlands.

Knowledge of the influence of mechanical stress on the critical current of superconductors is essential for magnet design. Due to prestressing, cooling and Lorentz forces, the windings of a magnet are stressed in both the axial and transverse direction. It is well known, that the current-carrying capacity of superconducting wires, especially with brittle materials like Nb_3Sn, can be largely reduced due to axial strain. In the case of uniform transverse loads, degradation effects are reported to be much more severe. Moreover, high local stresses are present in the superconductor, when the strands of a cable are pressed onto each other. This can result in a disappointing performance of the magnet.

In this paper, it is investigated to what extent the current-carrying capacity is diminished by transverse deformation of a wire. Two different types of test arrangements were constructed: the first one to apply a large compressive force up to 15 kN and the second one to investigate the low compressive force region. Results obtained with several types of Nb_3Sn wires are presented. Moreover, the internal stress distribution in a wire under influence of an external, compressive force, as analyzed with the finite element method program ANSYS, is dealt with.

11:30 NB-03 COMPRESSION STRESS EFFECT ON THE CRITICAL CURRENT OF Nb_3Sn CABLE-IN-CONDUIT CONDUCTORS, T. Ando, M. Nishi, H. Nakajima, T. Isono and S. Shimamoto, Japan Atomic Energy Research Institute, Ibaraki, Japan - The compression stress effect on the critical current of Ti alloyed Nb_3Sn cable-in-conduit conductors with different conduit wall thickness has been investigated. These conductors consist of 63 Ti alloyed Nb_3Sn strands inserted in the 316LN stainless steel conduit. The Ti alloyed Nb_3Sn strand produced by the bronze process has a diameter of 0.8 mm and a Cu/non-Cu ratio of 2. As the wall thickness of the conduit, 0.5, 1.0 and 1.5 mm are provided. A void fraction is 35 % for each conductor. These conductors were reacted for 200 h at 650 C. Each conductors were formed in U-type with a 700 mm length before heat-treatment. The conductors were compressed between two stainless steel anvil heads by a hydraulic machine power of 500 kg. The critical current measurement were carried out by voltage taps attached to the conduit in a 120 mm bore superconducting magnet. Firstly, the critical current as a function of magnetic field in the range of 10 - 12 T for three conductors has been measured without the transverse stress. As the results, the critical current of any conductor is around 70 % of sixty-three times the critical current of single strand. Namely, the critical current do not depend on the conduit wall thickness. Next, the critical current versus transverse compression stress for each conductor was measured at 12 T. The decrease rates of the critical current at 100 MPa for 0.6, 1.0 and 1.5 mm conduit wall thickness are 45, 20 and 3 %, respectively. Like this, Nb_3Sn cable-in-conduit conductors can be expecting for use in the transverse compression stress of more than 100 MPa by increasing the conduit wall thickness.

11:50 NB-04 THE EFFECT OF AXIAL STRESSES ON I_c OF SUBSIZE NET Nb_3Sn CONDUCTORS, W. Specking, A. Nyilas, A. Kling and R. Flükiger, Kernforschungszentrum, Inst. Techn. Phys., 7500 Karlsruhe, Federal Republic Germany

Under full load, the Nb_3Sn conductor of the toroidal field coils in the NET fusion reactor will have to withstand strong Lorentz forces: Axial tensile stresses of 140 MPa and radial compressive stresses reaching from 40 to 140 MPa necessitate a steel jacket with 40% of the conductor cross section. In order to study these effects on the 16kA/12T Nb_3Sn conductor developed at KfK, a subsize conductor at the scale 1 : 1.75 was fabricated. The effect of tensile stresses on I_c was measured by means of a newly designed strain rig, where currents up to 10 kA and forces up to 100 kN are simultaneously applied at fields up to 13 T at 4.2 K.

In this contribution, the 10 kA/100kN strain rig is described and the results of I_c vs. ε for several Nb_3Sn conductors are discussed. The variation of I_c with ε was measured at various stages of fabrication, i.e. for the basis Nb_3Sn strands, the flat cable with 31 strands, the cable with the Cu stabilizer and finally the complete conductor with the steel jacket.
The effect of transverse compressive stresses on I_c has been measured for the basis Nb_3Sn strands, thus confirming the strong degradation of I_c reported earlier, the latter being stronger for higher fields. An extension of the apparatus to measurements on cables and conductors is actually under work.

12:10 NB-05 DESIGN AND ANALYSIS OF A SUPERCONDUCTING CABLE-IN-CONDUIT TEST COIL FOR OPERATION AT 15 T AND 40 A/MM^2.* J.R. Heim, S.S. Shen, R.E. Patrick, J.R. Miller, M.R. Chaplin, J.A. Kerns, D.S. Slack, and L.T. Summers, Lawrence Livermore National Laboratory, Livermore, CA. USA

The International Thermonuclear Experimental Reactor (ITER) Design Team may use coil current densities as high as 40 A/mm^2 and peak magnetic fields of 12–15 T to size superconducting coils in a tokamak reactor design. To verify that these values are within the present superconducting magnet technology state-of-the-art, we are building a Proof of Principles (PoP) test coil. The PoP coil will be inserted into the bore of an existing High-Field Test Facility Solenoid magnet at LLNL. The PoP insert will be a solenoid coil with approximate dimensions of: 1-m outside diameter, 0.5-m inside diameter, about 0.5-m height. The overall coil fabrication will use the insulate-wind-react-impregnate method. The quartz-cloth-tape insulation material will be wrapped onto the conductor as part of the coil-winding process. The coil will be layer-wound using cable-in-conduit conductor (CICC) with all splices and connections located at the coil ends. The Ti-modified, internal-tin process, MF-Nb_3Sn technique will be used to produce the superconducting composite wire for the CICC. After reaction, the epoxy component of the insulation system will be added by vacuum impregnation. We describe details of the coil design and analysis and relate them to needs within the engineering data base supporting the design of magnet systems for ITER.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

SEPT. 1 (Fri) Session NC (poster) 10:50-12:30

I FUSION MAGNETS-3
II STABILITY AND RELIABILITY-3
Room P1 and P2

Chairman: J. Minervini, NET
Cochairman: F. Sumiyoshi, Kagoshima Univ.

NC-01 CONSTRUCTION OF NEW DIVERTOR COIL FOR JT-60, Y. Itou, T. Watanabe, H. Kamiya, K. Goto, T. Yonezawa (Hitachi), M. Shimizu, Y. Okumura, T. Koike, T. Ando (JAERI)

JAERI has been conducting the modification of JT-60 in order to investigate the improved plasma parameters. In the first stage of the modification, two major components were installed in the JT-60 machine. One is the new divertor coil for the lower X point plasma configuration and the other is the pellet injection system for plasma density profile control.
The new divertor coil was installed in very narrow space between the vacuum vessel and the support structures of the poloidal field coil (PFC), both of which were located in the toroidal field coil (TFC) bore. This location was selected in order to reduce the magnetomotive force of the coil making the null point in the vacuum vessel. The major parameters of the coil are listed below.

Coil diametor	6.32m
Magnetomotive force	0.896MAT (112KA x 8 turns)
Current density	53 ~ 76.8 A/mm^2
Cooling	Water direct cooling

Two different procedures of the construction of the coil were considered, namely dismantling the whole tokamak machine or not. For the reduction of the period of the construction as well as the cost, we have selected the non-dismantling procedure. Then the new divertor coil had to be divided into ten peices along toroidal direction, and these coil blocks were inserted through the narrow gap of two TFC units.
One of major issues of this modification was the connection of the coil blocks. Preceding the construction, a full scale four-turns mock-up was constructed and tested. We have confirmed the procedure of the installation and the dimension accuracy of the conductor array after the connection. By this mock-up test, we could also train the skillful workers.

NC-02 RELEVANCE OF TESTING SUPERCONDUCTING MODEL COILS FOR FUSION REACTOR APPLICATIONS, W. Maurer, Kernforschungszentrum Karlsruhe, Federal Republic of Germany

The discussion of testing superconducting model coils for fusion applications reveals discrepancies between the needed knowledge for the design of the magnet system for a future fusion reactor and the possibilities of future test stands. The investigations of test configurations lead to questions about the relevance of results coming from model coil test stands for big reactor coils. In this paper it is tried to elaborate these discrepancies, but also the common features and to define the gap between needs and possibilities. The development of testing criteria is undertaken and the role of boundary conditions is elucidated. Different possible test arrangements for model coils are discussed. The results of the LCT test are used in order to judge the significance of further test stands.
The LCT was the worldwide effort for the development of toroidal field coils for Tokamak reactors. The question to all planned tests will be about the new problems to be seen worth to be solved in a new expensive facility. One question is where LCT has left over doubts about magnet problems. Another question is what fundamental new arisen problems require new test facilities.

NC-03 STABILITY EXPERIMENT OF THE KFK POLOIDAL FIELD COIL CABLE, Tateishi H., Electrotechnical Laboratory, Ibaraki, Japan and C.Schmidt, Kernforschungszentrum Karlsruhe, Karlsruhe, F.R.G. In the frame of the poloidal field coil development for the French tokamak TORE SUPRA, we performed a stability test of the full size cable. The test arrangement is a hair-pin shaped closed loop of a cable. A transport current is induced into the loop by a superconducting transformer coil. A low-inductive dipole magnet is put on the straight part of the loop. Supplied with a capacitance discharge, it creates a half cycle sinusoidal field pulse of a duration between 3 and 30ms. In a typical experiment the sample is supplied with a constant transport current and the field pulse height is increased until a propagating normal transition occurs in the sample. The cooling conditions can be varied between liquid helium in a closed volume and supercritical helium. The stability limit of the cable is mainly determined by the transient heat transfer from the conductor surface into helium during a field pulse. Results are discussed quantitatively using a stability model, which was successfull in describing the stability of the basic conductor. The model compares the energy input into the conductor during a field pulse with the transient heat removal capability of the coolant. The stability limit of the cable is found to be well above the required value for TORE SUPRA but it is lower than the values expected from the stability model. The deviation can be explained qualitatively by the reduction of cooled surface and the occurrence of local hot spots in the cable, which is a consequence of the nonhomogeneous distribution of contact resistances between subcables.

NC-04 FURTHER PROGRESS IN THE MANUFACTURE OF THE US-DPC TEST COIL, M. Steeves, M. Hoenig, M. Takayasu, T. Painter, R. Randall, P. Marti, and J. Davin, MIT Plasma Fusion Center, Cambridge, MA, 02139 USA.

The US Demonstration Poloidal Coil (US-DPC) is being built by MIT for testing in early 1990 at the Japan Atomic Energy Research Institute (JAERI). Winding and heat treatment of the 2 m outer diameter Nb_3Sn coil are scheduled for completion in the summer of 1989. Insulation and final assembly will follow soon after. Parameters of the cable-in-conduit conductor and coil are briefly described. Manufacturing procedures and problems encountered in the fabrication of both the conductor and coil from August 1988 to August 1989 are considered. Included are descriptions of conduit fabrication and repair, helium inlet fabrication, tooling fabrication and coil winding, conductor termination fabrication for joints, and coil vacuum heat treatment.

NC-05 FABRICATION AND MECHANICAL CHARACTERISTICS IN EXPERIMENT OF THE Nb-Ti DEMO POLOIDAL COILS (DPC-U1,U2), H. Nakajima, K. Okuno, H. Tsuji, K. Yoshida, K. Koizumi, T. Isono, E. Yaguchi, and S. Shimamoto Japan Atomic Energy Research Institute, Ibaraki, Japan

The Demo Poloidal Coils (DPC-U1,U2) were installed in Japan Atomic Energy Research Institute (JAERI). One of the design concepts of the DPC-U1,U2 is realization of high mechanical performance. Therefore, the large cable-in-conduit conductor with rectangular cross section was designed and three kinds of the newly developed Japanese Cryogenic Steel (JCS) were applied to conduits of the DPC-U1,U2 (CSUS-JN1), supporting bolts (CSUS-JK1), and supporting structures (CSUS-JK2). The DPC-U1,U2 were fabricated through several steps such as strand and conductor fabrication, winding process, connection of winding, and so on. Some technical problems encountered during fabrication to achieve high mechanical performance. Fabrication of the DPC-U1,U2 progressed resolving these problems by developing special technique at each step. For example, pre-press technique was developed to remove conductor deformation of large conductors due to winding. Experiment of the DPC-U1,U2 was started on March. Displacements and strains of the DPC-U1,U2 and strains of the structures were measured with 12 extensometer and 92 strain gages in order to study the mechanical characteristics of the DPC-U1,U2. Measured results will be compared with the stress calculation using the Finite Element Method. This paper describes the fabrication and mechanical characteristics in the experiment of the Demo Poloidal Coils.

NC-06 THERMAL PERFORMANCE RESULTS OF THE Nb-Ti DEMO POLOIDAL COILS (DPC-U1,U2), E. Tada, K. Kawano, T. Ando, H. Tsuji, T. Hiyama, Y. Takahashi, M. Nishi, K. Yoshida, K. Okuno, K. Koizumi, T. Kato, H. Nakajima, T. Isono, H. Nisugi, M. Oshikiri, M. Yamamura, M Sato, I. Ito, J. Yoshida, N. Ito, Y. Wachi, and S. Shimamoto, Japan Atomic Energy Research Institute, Ibaraki, JAPAN

DPC-U1 and U2 are the superconducting pulse coils, consisted of the Nb-Ti cable-in-conduit conductor to investigate superconducting pulse-coil technology for Fusion Experimental Reactor (FER). Cooling conditions of these coils are designed as follows:

Mass Flow Rate per Channel	Mo= 18 g/s
Total Channel Number	Nc= 16 ch
Channel Length	Lch= 80 m
Inlet Temperature	Tin= 4.0 K
Inlet Pressure	Pin= 10 bar
Hydraulic Diameter	Dh= 0.0787 cm
Pressure Drop	DP= 0.72 bar

Total mass flow rate per coil is 288 g/s. Pressure drop measurement was conducted using a sample of the practical conductor in the verification test. As the results, the friction factor is determined as this formula:

$$1/\sqrt{f} = 0.87 \times \ln (Re \sqrt{f}) - 2.4$$

This paper describes cooldown and warmup characteristics, heat load of the coil, pulse operating performance in the view of thermodynamical performance, and pressure drop performance.

NC-07 POWER SUPPLY SYSTEM FOR THE DEMO POLOIDAL COILS T.Isono, K.Yoshida, Y.Ohkawa, K.Okuno, H.Tsuji, T.Ando, S.Takahashi and S.Shimamoto

JAERI,Naka Fusion Research Establishment,Ibaraki,Japan

Three power supplies were provided for the Demo poloidal coils (DPC) experiment. Two DC power supplies (30kA P.S. and 12kA P.S.) in Superconducting Engineering Test Facility (SETF) are used for DC operation. The JT-60 poloidal field power supply is employed for pulse (until 10 sec) operation. The JT-60 power supply and SETF are connected by 6.6kV cables, whose length is about 100 meters. Among many units of the JT-60 poloidal field power supply, the unit V(58kA, 5kV) and the unit F(92kA, 2.5kV) were connected to SETF for the DPC. The unit F can be used for bipolar operation but there are many restrictions at positive current. The unit V can be employed only for unipolar operation but it has better current controllability than the unit F. The DPC can be operated in many different modes by changing the combination and connection of these power supplies. The mode is changed by switches, which are composed of disconnectors and short bus bars. For quench detection, it is necessary to cancel inductive component of the coils. Therefore the co-wound compensation coils were installed in each pancakes. Furthermore, the mass flow meters of each pancake were also applied to detect flow choking during normal heat generation.

NC-08 FABRICATION OF DEMO POLOIDAL COILS, DPC-U1 AND U2, T.Ichihara*, T.Sasaki*, S.Takagi*, T.Minato*, T.Murai* Y.Tsuda*, T.Satow*, K.Okuno**, H.Tsuji**, Y.Takahashi**, M.Nishi**, K.Yoshida**, H.Nakajima**, and S.Shiamoto**

The two Demo Poloidal Coils, DPC-U1 and U2 of over 30MJ stored energy using NbTi cable-in-conduit conductor of 7T and 30kA rating have been completed and installed in JAERI Demo Poloidal Coil Facility (DPCF). New winding technology was applied to the coils to ensure mechanically high winding stiffness with good contact between turns avoiding distortion of 29x35.5 mm conductor. Conductor joints were made by soldering with strand-to-strand overlapping contact satisfying 1W joule loss each. Joints of conductor conduit were welded with low heat TIG ensuring no damage to the critical current characteristics of the conductor strands and all welded joints in over 1.6 km long Helium passages were Helium-leak tested under the design pressure. Glass-polyimide taping for ground insulation was applied for ac 16kV tension test. Japanese Cryogenic Steel (JCS) support structures were assembled with the coils to suppress any motion caused by 28MN magnetic force.

*Mitsubishi Electric Corp., JAPAN, **Japan Atomic Energy Research Institute(JAERI)

NC-09 DEVELOPMENT OF SUPERCONDUCTORS FOR THE DEMO POLOIDAL COILS (DPC-U1, U2). T. Kumano*, N. Aoki*, M. Ichihara*, E. Suzuki*, Y. Nakabayashi**, F. Fujiwara**, T. Sasaki**, T. Ichihara**, T. Satow**, H. Tsuji***, H. Nakajima***, K. Okuno***, Y. Takahashi***, and S. Shimamoto***,

NbTi cable-in-conduit conductor of 7T and 30kA rating for the two Demo Poloidal Coils (DPC-U1, U2) of over 30 MJ stored energy have been developed. This conductor consists of $3^4 \times 6$ strands and Japanese cryogenic steel (JCS) conduit and was produced by double-packing of CuNi, Cu and NbTi elements into CuNi pipe and subsequent hydrostatic-extrusion and drawing to final diameter of 1.1mm. Polyvinyle formvar of 10μm in thickness was coated over the strand to eliminate coupling losses between strands. With above configuration of conductor, a time constant of AC loss was quite small and critical current density was about 1150A/mm^2 at 7T, though the matrix ratio was so large as NbTi:Cu:CuNi=1:3.3:1.3. The assembly of 8 pieces conductors, the size of which is 29 × 35.5mm, was completed by specializing the equipment to enable forming and sizing to be done in tandem. The conduit was seamed with TIG welding and the conductors of full length were tested with eddy current and dye penetration methods.

* Showa Electric Wire & Cable Co., Ltd, Japan.
** Mistubishi Electric Corp., Japan.
*** Japan Atomic Energy Research Institute (JAERI)

NC-10 Fabrication of DPC TJ, a Forced-Cooled Large Superconducting Coil.
H. Mukai, O. Osaki, T.Hamajima, M. Naganuma, H. Shiraki, T. Fujioka,
Toshiba Corporation, Yokohama, Japan
M. Nishi, Y. Takahashi, H. Tsuji, T. Ando, S. Shimamoto,
Japan Atomic Energy Research Institute, Ibaraki, Japan

The DPC-TJ coil, forced cooled superconducting coil, developed by Toshiba and Japan Atomic Energy Research (JAERI) in collaboration, aiming at the development of the toroidal coil of the Fusion Experimental Reactor (FER), is now in the final stage of fabrication. The coil, characterized by double walled cable-in-conduit conductor so called "Preformed Armor Type CICC", has operating current of 24KA, average current density of 40A/mm2, design field of 12T and is composed of two double pancake windings with I.D. of 1000mm. The 1st conduit (inner one) has a role as the leak tight boundary while the 2nd conduit (outer one) has a role as the supporting member against electromagnetic force and/or internal pressure rise. 486 Nb3Sn strands packed in the 1st conduit are heat-reacted by W&R method, and then are encased into the 2nd conduit fabricated by machining. Therefore, it has many advantages compared with the conventinal type coil as follows, small Jc degradation of Nb3Sn because of W&R method and small thermal contraction stress on Nb3Sn wire(1), no performance degradation of the 2nd conduit material because of experiencing no heat treatment(2), realization of excellent accuracy in size and high rigidity of the 2nd conduit because it is made by machining(3). The DPC-TJ coil is planned to be tested background field from the DPC-U1, U2 coil at JAERI around this summer. This paper presents the detail explanation about the fabrication of the DPC-TJ coil.

NC-11 RESULTS OF VERIFICATION TESTS AND COIL TEST OF DPC-TJ,
M. Nishi, H. Tsuji, Y. Takahashi, H. Nakajima, T. Isono, T. Ando, S. Shimamoto,
Japan Atomic Energy Research Institute, Ibaraki, Japan
H. Mukai, T. Hamajima, H. Shiraki, T. Fujioka,
Toshiba Corp., Yokohama, Japan,

The DPC-TJ coil is a large Nb3Sn coil (1.0 m I.D., 1.8 m O.D., 0.1 m L) developed by the collaboration between Toshiba and JAERI as one of the test coils in the DPC program. The main purpose of the DPC-TJ coil development is to demonstrate the realization of a high-field superconducting coil (12 T) with high average current density (40 A/mm2) using a large-current conductor (24 kA) which meets the requirements for the superconductor of the toroidal coil of the next generation huge tokamaks such as the Fusion Experimental Reactor(FER) in JAERI. The DPC-TJ coil is the first test coil using the preformed armor type CICC conductor, therefore, the verification of the effectuality of this new type conductor is also its important purpose. The preformed armor type CICC is composed of a normal cable-in-conduit conductor with thin first conduit and a second conduit (armor) which covers the first conduit. The armor, whose role is mechanical supporter, is formed to the coil-shape preliminary by milling machine without bending procedure, and a reacted coil-shape cable with the first conduit is put in it. Various problems in the process of fabrication of large current coils, such as the problem of bending a conductor with thick and hard conduit, are settled by this preformed armor method. The DPC-TJ coil itself is almost completed and is scheduled to be tested in the DPC facility before long. This paper presents the results of various verification tests and the coil test.

NC-12 VERIFICATION TESTS OF THE Nb_3Sn DEMO POLOIDAL COIL (DPC-EX),
Y. Takahashi, T. Ando, M. Nishi, H. Tsuji, T. Hiyama, K. Okuno, K. Yoshida, H. Nakajima, K. Koizumi, E. Tada, T. Kato, T. Isono, K. Kawano, and S. Shimamoto
Japan Atomic Energy Research Institute, Ibaraki, Japan

The DPC-EX coil is a Nb3Sn coil to demonstrate high stability margin showing the potential capability of Nb3Sn for pulse coils. The coil has the inner diameter of 1 m, the outer diameter of 2 m, the design field of 10 T, and the nominal current of 10 kA. This coil will be tested between the DPC-U1 and the DPC-U2 which are produced using a NbTi pulsed conductor. The conductor of the DPC-EX coil is a cable-in-conduit conductor which is composed of Nb_3(SnIn) strands. This conductor has a main- and a sub-cooling-channel. These channels are connected by a mixing-cooling-channel.

Many verification tests are carrying out for this coil. The pressure drop of a full-size conductor was measured at 80 K and 4 K level. The measured pressure drop par one cooling-path at 4 K level and 10 atm is 0.7 atm with flow rate of 10 g/s. This value is less than a capacity of the DPC facility. The critical current of the full-size conductor was measured up to 11 T. The measured critical current is 16.5 kA at the design field of 10 T. This value meets the design criteria. This paper will be described these results.

The bundle of the superconducting strands has been fabricated. The assembling of the bundle and the conduit are starting now.

NC-13 DESIGN STUDY OF FER SUPERCONDUCTING MAGNET SYSTEM
K. Yoshida, K.Koizumi, M. Shugimoto, K. Okuno, E. Tada, H. Tsuji, M. Hasegawa, S. Matsuda, and S. Shimamoto,
Japan Atomic Energy Research Institute,Naka-machi, Naka-gun, Ibaraki-ken, 311-01 JAPAN -- Primary design studies of the Fusion Experimental Reactor(FER) are in progress at Japan Atomic Energy Research Institute (JAERI). The superconducting magnet system is most important component to generate high performance plasma in the FER. Specifications of the toroidal field coils (TFC) and ohmic heating (OH) and equilibrium (EF) of the poloidal coils (PFC) are as followings:

	TFC	PFC-OH	PFC-EF	
Bmax	12	12	7	T
Iop	30	30	30	kA
Number	12	8	6	
dB/dt	20-40	2	2	T/s

On the TFC, insulation dose is 10 MGy and Nuclear heating is 5 kW/m^3. The forced flow cooling conductors are selected for all of coils mechanical and electrical insulation (20 kV) requirements. The electrical, mechanical, and thermal designs of superconducting magnet system of the FER are described in this paper. Especially, the quench protection analysis is studied to optimize current density of conductor area. And the mechanical stability of wedge supporting method for the TFC centering force is analysis by the finite element method.

NC-14 Japanese Design of ITER Superconducting Magnet System
M.Hasegawa, K.Yoshida, K.Koizumi, K.Okuno,
Y.Takahashi, E. Tada, H.Tsuji, Y.Shimomura
Japan Atomic Energy Research Institute, Ibaraki, Japan

The design of International Thermonuclear Experimental Reactor (ITER) was started in Mar. 1988 and is in progress also in Japan. In this design, the toroidal (TF) and poloidal (PF) coil design is one of the most important design items. Because ITER is to have both long pulse ignition and steady state operation, it is essential that the magnets are superconducting to achieve the necessary performance (field and current density) and minimize power consumption.

The magnet system should satisfy the certain design requirements which enable the tokamak to achieve the minimum capability and be consistent with other machine systems. These requirements are :

Toroidal field at plasma center	>	5.3 T
Field ripple at plasma edge	<	1.5 %
Steady state operation	>	hours
External supply magnetic flux	>	280 Vs.
Insulation Dose		20 MGy
Nuclear Heating		1 kW/m^3
dB/dt at disruption		20 - 40 T/s

Since the rated maximum filed strength of the TF and central solenoid coils is 12 T, the superconductor based on $(NbTi)_3Sn$ is selected with a critical current density of 800 A/mm^2 at 12 T, 4.2 K and zero strain. For the equilibrium coils, a NbTi-superconductor is adopted because of a magnetic field requirement lower than 7 T. The forced-flow cooling concept by supercritical helium is selected for all of coils from the mechanical and electrical insulation requirements.

NC-15 **WITHDRAWN**

NC-16 FIRST CONSTRUCTION OF A SUPERCONDUCTING HELICAL COIL FOR A FEASIBILITY STUDY OF LARGE HELICAL COIL, Y. Tuda, K. Toyoda, T. Hirayama, S. Kida, K. Kuno, Mitsubishi Electric Corporation, Kobe, Japan, T. Mito, J. Yamamoto, Kyoto University, Kyoto, Japan, M. Takeo, Kyusyu University, Fukuoka, Japan, A. Iiyoshi, O. Motojima, Y. Takeiri, I. Ohtake, Institute for Fusion Plasma Science, Nagoya, Japan

We succeeded in constructing the first superconducting helical coil. The fabricated helical coil has the major radius of 300mm, the minor radius of 64mm, the poloidal pitch number of 16 and the central magnetic field of 2T at the nominal current of 775A. The number of helical coils is 2 and one coil is 11 turns × 22 layers in a cross section of 36.3mm × 47.9mm. The average current density is 110A/mm^2 and the stored energy is 76.5kJ. The coil scale is small but it is meaningful because of the first helical coil using a superconducting wire (NbTi/Cu). The main purposes of this coil is a feasibility study of a large superconducting helical device (The present design parameters are the major radius of 4m, the minor radius of 0.96m, the poloidal pitch number of 10 and the central magnetic field of 4T). This device is planned to be constructed until 1995 as a main experimental apparatus of Institute of Fusion Plasma Science (tentative name). In order to simulate the construction technique of a large helical coil, this small-scale helical coil was wound with the computer controlled winding machine which was developed for the automatic helical winding. We gained useful technical data about the fabrication of a superconducting helical coil and confirmed a feasibility of a large superconducting helical device.

NC-17 FUNDAMENTAL DESIGN OF LARGE HELICAL DEVICE WITH POOL-COOLED SUPERCONDUCTING MAGNETS, S. Suzuki, S. Imagawa, H. Miyazawa, R. Saito, F. Iida, H. Ogata, (Hitachi) O. Motojima, A. Iiyoshi, M. Fujiwara, K. Yamazaki, (Nagoya Univ.) M. Takeo (Kyushu Univ.), and Large Helical Design Team

The Large Helical Device is a next generation helical equipment for poloidal coils. The large scale superconducting magnets are going to be applied for these coiles.

The major and minor radius of helical coil system are 4m and 0.96 m respectively and the magnetic filed is 4T at plasma center and 8T at the coil surface. The coil system stores about 2GJ of total energy. Superconductor of helical coil is pure aluminum stabilized Nb-Ti compacted strand cable with copper housing. The coils have the helium can made of stainless-steel and this can is filled by liquid helium. This pool-cooled superconducting helical coil system satisfies the fully stabilized condition.

The superconducting poloidal coils are composed of six (three pairs) circuler coils and use forced-cooled superconductor to reduce the eddycurrent losses by the field changing operation.

The helical and poloidal coil systems are built in the large bell -jar (Vacuum vessel for thermal insulation) with outer diameter of 13m.

This paper descrives conductor design and stability of superconducting magnet for helical and poloidal coil systems.

NC-18 STRUCTURAL ANALYSIS OF FORCED-COOLED SUPERCONDUCTING HELICAL COIL FOR LARGE HELICAL DEVICE

K.Kitamura,M.Shibui,K.Yamamoto,K.Nakamoto,H.Takano and S.Ioka
Toshiba Corporation,Yokohama,Japan
O.Motojima,A.Iiyoshi,M.Fujiwara,Y.Takeiri,K.Yamazaki, M.Takeo and Large Helical Design Team
Planning Office for Institute of Fusion Plasma Science,Nagoya University,Nagoya,Japan

The Large Helical Device(LHD) is a heliotron/torsatron type device with a major radius of 4 m,helical coil minor radius of 0.96 m and helical multipolarity of 5. A forced-cooled superconductor has been proposed for use as helical field coils of the LHD,where high structural integrities are especially required. To design the helical coils and their support structure with high reliabilities,a knowledge of detailed mechanical behavior of helicalcoils and their support structure is of great importance.

Detailed structural analysis of the helical coil for the LHD has been performed where two-step analytical method is applied. In the first step analysis,the 3 D overall model has been set up to understand global mechanical behavior of helical coil,its support structure and overall force ballance.

In the second step,the 3 D conductor model has been made to investigate load transmission between conductor turns and to assess structural reliabilities of conductor conduit and insulators.

NC-19 THE RFX OHMIC HEATING COILS: DESIGN OF THE ELECTRIC TERMINALS AND BUSBARS, F. Bellina, G. Chitarin, P. Zaccaria, Istituto Gas Ionizzati - Associazione EURATOM CNR ENEA, Padova, Italy.

RFX is a fusion machine based on the toroidal magnetic confinement. The Ohmic Heating (OH) coils of this machine operate at 50 kA current and produce a maximum induction value of 4.5 Tesla. These coils are arranged in four groups and each group is fed by an independent busbar system. The peak energy stored in the magnetic field produced by OH coils during the machine operation is 72 MJ. In case of a fault this energy may be suddenly released in the faulty component, therefore reliability had to be one of the main goals of the OH system design. Since the electrical terminals of the OH Coils are located in the high field region of the machine, both the terminals and the feeding busbars are subject to a high electromagnetic load, which may involve severe mechanical stresses. From a preliminary analysis, the most critical sections of the structure revealed to be the bolted joints between busbars and coils, and the copper-insulation interface in the region of the coil terminals. The field configuration, together with the geometry of the busbars, give rise to a very complex load distribution, which required the use of the finite element method to perform a detailed stress analysis. A number of detailed stress analyses on several possible design solutions has shown that stresses can be remarkably reduced with a careful choice of the busbar route and shape. In the paper the basic design criteria, the analysis procedure and results, together with the manufacturing solution are exposed in detail.

NC-20 FAULT PROTECTION OF THE RFX MAGNETIC SYSTEM, P. Campostrini, G. Chitarin, M. Guarnieri, A. Stella, Istituto Gas Ionizzati C.N.R-EURATOM Association & Department of Electrical Engineering, Padova, Italy.

The Magnetic System (MS) of the Reversed Field Pinch Experiment RFX (2 m and 0.5 m major and minor radii, 2 MA plasma current) is formed with three windings (W): the Magnetizing W (40 coils) and the Field Shaping W (16 coils), which are both part of the Poloidal Field System, and the Toroidal W (48 coils). They can store 76 MJ, with a peak power release up to 7 GW and discharging times of 50 ms. Either the poloidal and toroidal electrical circuits present complex topologies, due to technological and operational requirements.

Due to the high energy and power levels, faults occurrence in the Magnetic System or in other sub-systems (power supplies systems, plasma systems) can involve devastating effects in many machine sub-systems, particularly in MS, if not effectively controlled. Moreover the extensive analysis of possible faults, performed through several simulations of different circuit scenarios, showed that protective actions must be very quick in order to be effective: interventions within 1 - 2 ms are compulsory for most short circuit faults.

Fault protection in RFX Magnetic System is based on two criteria. The first consists in minimizing the probability of fault occurrence: this is achieved through a *built-in realibility* of the windings, which have been specified, designed, constructed and tested to withstand voltages much higher than those in normal operation. The second criterion consists in the fast inhibition of the fault evolution: this is performed by an *active fault protection* relying on a sophisticated, and to some extent innovative, protection system: the Fast Protection General System SGPR, able of producing very fast protective actions (within 1 - 2 ms) on the whole machine. In order to activate SGPR, the Magnetic System is equipped with a fast fault sensor systems able of detecting the fault occurrence, identifying the fault severity and requiring protective action, within less than 0.5 ms. This paper presents the whole scenario of protection problems in MS. In particular it describes the development work on the MS fault sensor system and shows its main operating and design features.

NC-21 ANALYSIS OF FRICTIONAL HEATING IN SUPERCONDUCTING BUNDLES FOR MAGNETS FOR FUSION REACTORS, B. Schrefler, R. Gori and G. Zavarise, Istituto Scienza e Tecnica delle costruzioni, Padua University, Italy.

Recently proposed conductors for high magnetic fields for both toroidal and poloidal field coils for tokamaks for fusion research belong to the so called cable in cunduit type: the superconducting cable bundle is made of twisted and braided strands of superconductive wires, distributed over the whole area of the conduit, and liquid helium flows through the interstices of the cable bundle.

During operation the conductor is subjected to time varying forces resulting in differential movements between the strands. These movements can give rise to frictional heating. Furthermore, in both TF and PF coils the conductor is subjected to high transverse loading. If the corresponding transverse strain is transmitted directly to the superconductor this could produce degradation of the current carrying capacity.

In this paper an analythical approach is presented to investigate the behaviour of twisted wire cables. Also a numerical finite element analysis, with contact elements and large displacement, is performed to describe the bundle behaviour. Some parametric analyses and an application for a recently proposed NET conductor are shown.

NC-22 A GEOMETRIC SCALING LAW OF QUENCH PROPAGATION VELOCITY IN EPOXY-IMPREGNATED SUPERCONDUCTING WINDINGS,

A. Ishiyama, K. Urayama, M. Kawamura and Y. Iwasa†,
Department of Electrical Engineering, Waseda University, Tokyo, Japan

We have been developing computer codes to describe quench process in multi-section, epoxy-impregnated high field superconducting solenoids. The codes rely on field and current dependent quench propagation velocity data in the transverse (turn-to-turn) direction. In this paper, quench velocity, both longitudinal and transverse, for NbTi and Nb_3Sn superconducting winding models are analyzed by the finite element method. The models are prepared with a conductor wound into a one-layer, epoxy-held, noninductive form; experimental velocity data are taken with the model placed in an adiabatic chamber. The results show good agreement between the finite element analysis and quenching experiments. We have correlated transverse velocity data in terms of longitudinal data and used this correlation to develop a geometric scaling law to predict propagation velocities for other conductors.

† Francis Bitter National Magnet Laboratory, MIT, Cambridge, MA, USA

NC-23 METHODS FOR CALCULATION OF QUENCHING PROCESS OF THE SUPERCONDUCTING MAGNET OF THE HIGH GRADIENT MAGNETIC SEPARATOR, Yan Luguang, Lei Yuanzhong, Yi Changlian, Institute of Electrical Engneering, Academia Sinica, Beijing China

The magnet of The High Gradient Magnetic Separator consists of three solenoid coils which have the inner diameter of 0.6m, the length of 0.234m. The stored energy of the magnet is 3MJ and the current is 1200A. In order to have enough stability and reliability, the magnet is wound with narrow helium channels between layers. These channels make the quench propagation velocity several times smaller than that of close-packed magnets. To prevent the magnet from burning out or electrical breaking down, the magnet should be discharged as soon as possible in case of quenching. When only a energy dumping resistor is used, the discharge time constant is long because of the big magnet inductance and the low permissible terminal voltage, leading to high hot-spot temperature and high internal voltage. if at the same time the three coils are shunted by resistors respectively, hot-spot temperature and internal voltage will be greatly reduced. This paper describles the two methods used for calculation of quenching process and the results obtaind for protection design.

NC-24 NUMERICAL CALCULATION OF QUENCH ENERGY OF THE ADIABATIC SUPERCONDUCTING MAGNETS, D.L.Zha, S.Han, L.Z.Lin, Institute of Electrical Engineering, Academia Sinica, Beijing, China

This work investigates the transient stability of adiabatically stabilized superconducting magnets. We solved the time dependent heat balance equation in numerical method and developed a program to calculate the minimum quench energies of densely-packed and potted coils. The magnet was treated as an anisotropic three-dimensional continuum and its radial and axial heat transfer were fully considered. The results were compared with available experimental data (Scott's) and agreement was fair. We compared the results from different calculating models and concluded that a perfect physical model is most important. We have wound a Nb_3Sn magnet with inner diameter of 60mm and determined the minimum quench energy in various magnetic field and electrical current. The data were also compared with calculating results.

NC-25 DOUBLE-CASCADE PROCESS OF THE NORMAL ZONE PROPAGATION IN MULTISECTIONAL SUPERCONDUCTING SOLENOID, V.V.Matokhin, O.A.Kleshnina, A.A.Konjukhov, V.A.Malginov, P.N.Lebedev Physical Institute of the AS USSR, Moscow.

The quenches of the 82-sectional superconducting solenoid having the epoxy impregnated Nb-Ti/Cu winding were investigated. The dimensions of the winding were: a1=35,8 cm, a2=45,4 cm 2b=18,0 cm. Normal zone was initiated by local heater placed at central or side turn of the inner layer. The main signals registrated during the quench were the voltages across the layers shunted by the low-ohm resistors, the changing of the magnetic field at the geometrical center of the solenoid and the voltages from the thermocouples located along the cross-sectional perimeter of the winding. On the basis of the signals the picture of the normal zone propagation was created and the magnetic field values at the different points of the central and side planes of the winding were calculated. It is determined the normal zone propagation mechanism has changed by jump from the slow process of heat transfer between layers to rapid electromagnetic "avalanche". This effect connected with a second time arising of the normal zone at the side plane of the winding. The begining dimension of this zone was less or equal 0.3 cm (three layers) in radial direction. When the initial current of the quench was increased the region replaced to inner layers. Moreover the radial position of the second time arising of the normal zone didn't depend on the position of the heater at inner layer. Some reasons of the second time arising of the normal zone were analysed.

NC-26 PROPAGATION OF NORMAL ZONES IN AN AC SINGLE-LAYER SUPERCONDUCTING COIL, K. Funaki, Y. Tokunaga, M. Iwakuma, M. Takeo and K. Yamafuji, Faculty of Engineering, Kyushu University, Fukuoka, Japan

Two-dimensional propagation of normal zones has been studied experimentally in a single-layer superconducting coil with 60 Hz transport current. The winding used was a NbTi multifilamentary wire with CuNi matrix. Propagation velocities in the directions both parallel to and purpendicular to the wire axis were individually measured by potential taps within a sufficiently short time interval compared with one cycle of the AC current. It was found experimentally that the propagation velocities averaged during the short time interval almost coincided with steady ones for the same coil with the direct current equal to the mean value of the AC current in the corresponding period. This means that the propagation of the normal zone was directly related with the instantaneous value of the transport current.

The longitudinal propagation along the wire was quantitatively explained by usual theoretical expressions for the adiabatic propagation in single wires. The transverse propagation from turn to turn, however, was not evaluated from the longitudinal one with the anisotropy in heat conductivity in the single-layer coil.

The transverse propagation was numerically simulated as the propagation in an alternating layer-structure composed of conductor and insulation layers. The numerical simulation shows that difficulty in theoretical estimation of the transverse propagation originates from non-steady heat flow in the insulation layers. This tendency becomes dominant in the case where the residual resistivity of the wire is very high because of rapid increase in temperature of the conductor after transition to the normal state.

NC-27 PERFORMANCE OF Nb3Sn TAPE COIL COOLED BY SOLID CONDUCTION, Y. Matsubara, T. Ogasawara, M. Kaneko, M. Furuyama, H. Yamamoto and M. Tanaka, Nihon University, Funabashi-shi, Chiba 274, Japan.-- This paper described the experimental results of the wax impregnated double pancake coil made by Nb3Sn tape conductor, which is cooled by solid conduction by means of copper plate connected to the refrigerator. The used conductor was 5 mm in width and 75 μm in thickness. The coil size was about 80 mm in an outer diameter and about 30 mm in an inner diameter. The stability of edge-cooled tape conductor is limited by the magnetic field perpendicular to the wide face of the conductor. This is mainly due to the higher critical current density, Jc, at the lower magnetic field, because the limiting current density of stability, Js, may not exceed Jc at the lower magnetic field, due to the limited cooling performance of the conductor. However if the higher cooling temperature has been used, the stability may increase due to the decrease of Jc. Our experimental results of the test coil show that the cooling temperature of about 10 K gives the maximum stable operating current of the coil. The operating current was restricted by the decreasing critical current of the conductor if the cooling temperature above 10K was used. Below 10 K, the quench occured at current levels less than short sample critical values. As the results, stable operating current rather decreased with decreasing temperature. These temperature dependency has been predicted theoretically. The maximum magnetic field perpendicular to the tape face was about 2 T when the cooling temperature was about 10 K.

NC-28 EXPERIMENTAL VERIFICATION OF DYNAMIC STABILITY OF FACE-COOLED SUPERCONDUCTING TAPE, H. OHKUBO, T. NOGUCHI, Y. MASTUBARA†, T. OGASAWARA†, VACUUM METALLURGICAL CO., LTD., *NIHON UNIVERSITY

The dynamic stability techniques of superconducting tapes depend so far on the edge-cooling resuluting in low current density operation of the nagnet. Recently one of the authors(T.OGASAWARA) presented an exteded analysis of the dynamic stability that will make possible high current density operation under a condition of the face-cooling.

Based on that analysis, an experment has been done to verify the dynamic stability of face-cooled samples having sabilizing copper sheets of different thickness. The highest stable current density Js predicted from the analysis agreed well with the experimental results.

NC-29 TOROIDAL COILS ANALYSIS UNDER FAULT CONDITIONS WITH NON-UNIFORM CURRENT DISTRIBUTION, I. Montanari, P.L. Ribani, Facoltà di Ingegneria, Università di Bologna, Italy.

This paper illustrates a mathematical model which describes the toroidal magnet of a tokamak under fault conditions. The model is derived by means of the field theory, using the integral approach, and it allows to calculate the currents and the temperatures distribution inside the coils during the short circuit of one of them. The model is of quasi one-dimensional type and the parameters are time dependent. The solutions are obtained by means of finite elements method. The discretized dimension is the radial one. The current and temperature distribution are considered to be uniform along the toroidal direction, while the dependence on the azimuthal co-ordinate is analytically taken into account. The results also are presented here in comparison with those computed by means of the model based on the circuit theory in which the current was considered uniformly distributed.

SEPT. 1 (Fri) Session ND (oral) 14:00-16:20

SUPERCONDUCTING GENERATORS AND MOTORS-2
Room A

Chairman: P. Weymuth
PSI

Cochairman: Y. Murakami
Osaka Univ.

14:00 ND-01 SELF ENERGIZED AIR CORE SUPERCONDUCTING (SEAC) MOTOR, M. A. Hilal and J. D. Lloyd*, Applied Superconductivity Center, University of Wisconsin, Madison, WI 53706, USA

The discovery of oxide superconductor is expected to greatly impact the design, the specific power and the efficiency of electric motors. The weight saving is realized by eliminating magnetic materials since high magnetic fields can be efficiently generated. The use of superconducting material will lead to significant reduction in windings I^2R and eddy current losses. Hysteresis losses in magnetic materials will also be eliminated. Synchronous and induction motors are widely used as intermediate size motor drives. Conventional designs are not appropriate for superconducting motors and cannot fully utilize the unique properties of superconducting materials. For example, merely replacing the rotor windings of a conventional three phase induction motor with a superconducting winding is not adequate. Whereas having the rotor conductor large enough to carry the startup induced current without going normal will produce zero torque, using a small conductor may result in driving the rotor winding normal in a non-controllable manner during the motor startup. The use of three phase synchronous motor will not have such drawbacks but brush elimination will be of great advantage. A motor design is presented in this paper. It has no brushes, the rotor windings are energized using a flux pump scheme, and it operates like a synchronous motor following the startup mode. The advancements in SCR electronics make such designs practical as well as provide means for speed control and result in reducing the motor reactive power. Other means of switching will be discussed.

*Emerson Motor Technology Center, Emerson Electric Co., St. Louis, MO, USA

14:20 ND-02 SPECIFICATIONS AND SELECTING PROCEDURES ON SUPERCONDUCTING FIELD WINDINGS OF SUPERCONDUCTIG GENERATORS.
K.Uyeda, S.Meguro, T.Saitoh, K.Takahashi, H.Kubokawa, Engineering Research Association for Superconductive Generation Equipment and Materials (Super-GM), Osaka, Japan
R&D program on the superconducting generator at Super-GM includes three types of NbTi superconducting field windings as the main superconducting component. At the same time, more advanced generators towards the future are taken into the program as the basic research , such as static Nb_3Sn field winding model and superconductor development for AC armateur winding. Each type of NbTi field windings is carefully positioned to cover the whole aspects of the key technologies required for the practical machine:thermal and mechanical stability, high current density, reduction in AC losses etc. This paper describes the target specifications of NbTi and Nb_3Sn superconductors used for field windings of superconducting model rotors and the selecting procedures of optimum superconductor from two or three promising ones as one of the most important R&D subjects executed by both of generator and superconductor development groups under the promotion of Super-GM. Repetitive checks and reviews are scheduled based on the research progress until the final choice of the design in order to utilize the most up-to-date results in the model rotors to be constructed between F.Y.'91~'93.

*This work was supported and funded by NEDO(New Energy and Industrial Technology Development Organization).

14:40 ND-03 CURRENT SITUATION OF R&D ON SUPERCONDUCTING GENERATORS CARRIED OUT BY ENGINEERING RESEARCH ASSOCIATION FOR SUPERCONDUCTIVE GENERATION EQUIPMENT AND MATERIALS.
T. Tanaka, S. Hirose, M. Tanaka, T. Kitajima and M. Sunada, Engineering Research Association for Superconductive Generation Equipment and Materials (Super-GM), Osaka, Japan.
Super-GM was established on October 1, 1987 in order to promote the research and development(R&D) on applications of superconducting technology to electric power apparatuses, based on the result of feasibility studies for superconducting generator carried out in 1985 and 1986 as the moonlight project sponsored by AIST, MITI. Super-GM R&D project sponsored by NEDO will be conducted during eight-year period from FY 1988 by verifications with elementary technology models, partial models and model machine of superconducting generator, including R&Ds of superconductor for generator, refrigeration system and total systems. As to the superconducting generator, two kinds of excitations, a high response and a low response, were applied to generator designs, and the manufacturing and testing of 70MW class machine was planned as a series of R&D for 200MW class superconducting generator. Conceptual designs of 200MW class generators were carried out in FY 1987 and a R&D with some of the elementary technology models was carried out in FY 1988. This paper describes the outline of the R&D plan of superconducting generator in the Super-GM and the latest status of the program mainly on the superconducting magnet of the generator field winding.

15:00 ND-04 DESIGN AND MANUFACTURE OF SUPERCONDUCTING GENERATOR WITH HIGH RESPONSE EXCITATION.
T. Okada*, T. Nitta*, S. Hayashi**, K. Saikawa**, M. Tari*** and M. Kumagai***, *Dept of Elect. Eng., Kyoto University, Kyoto, 606, Japan, ** The Kansai Electric Power Co. Inc.,Osaka 530, Japan, ***Toshiba Corporation, Yokohama, 230, Japan.
We are studying design and power system characteristics of superconducting generator with high response excitation. A superconducting generator with high response excitation has been constructed and tested. The specification of the generator is; 100 kVA, 220 V, 1800 rpm and 300 V of ceiling voltage. The features of the machine for high response excitation are: 1)Three-component composite of NbTi/Cu/CuNi for field winding, 2)Coil retaininig cylinder of inconel 718 with high strength and high resisitivity, 3)Good property of damper (outer rotor) for high response excitation and disturbances of power system, and so on. This paper describes the design, the structure, the experimental system with monitoring and protective systems, component model tests and basic tests(no-load and short circuit characteristics, zero-sequence reactance, negative-sequence reactance, sudden three phase short circuit test, on-load test and so on).

15:20 ND-05 FULLY SUPERCONDUCTING AC GENERATOR WITH BRUSHLESS EXCITATION SYSTEM.
I.Muta, H.Tsukiji, T.Hosino, E.Mukai and T.Furukawa, Department of Electrical Engineering, Saga University, Saga-shi, Japan
A common scheme of superconducting AC generators developed so far is wellknown to be of rotating field type in which a field excitation power is supplied through collector ring system. However, the newly-developed excitation system by us is capable of not only eliminating such a system, but also making the field circuit " persistent current mode " along with adjusting its magnitude. In addition, the output coil say armature winding is made of superconducting wires with very low ac loss. Thus we have developed a so-called brushless fully superconducting generator capable of producing the electric output of less than 20 kW. Experimental results, adopting magnetic flux pump system to the field circuit, have proved that: 1) Growth rate of pumped-up field current tends to decrease with an increase with an increase of magnitude of the current. 2) Growth rate of pumped-up field current tends to increase in proportion to a velocity of travelling magnetic field acted on the flux pump, but having its limit. 3) From point view to achieve the maximum growth rate of the pumped-up field current there appears to be an optimal value of flux pump excitation. 4) Quench current of the superconducting field circuit seems to be about 70 A. Next, the following results from grnerating test are obtained: 5) No-load and load characteristic curves agree well with the designed ones. 6) Output voltage waveforms at both no-load and load are of good sinusoidal form. 7) Electrical output of about 2.3 kW to date was gained at 50 Hz when the prime mover of 2.9 kW drove the generator. However, taking account of critical currents of superconducting armature and field windings adapted, the output power are thought to grow up to around 20 kW.

15:40 ND-06 SUPERCONDUCTORS AND RARE EARTH MAGNETS : AN EXCITING COMBINATION FOR ELECTRICAL MOTOR.
P. Tixador, Y. Brunet , P. Brisonneau, CNRS-CRTBT/LEG , Grenoble, France.
Due to the technological progress on ultra-fine NbTi filaments associated to a high resitive matrix the use of superconductors (S.C.) at industrial frequencies (50/60 Hz) is now possible. 50 Hz losses in the best a.c. S.C. wires do not exceed 20 kW/m^3 for 1 T peak value magnetic induction. The first applications of these wires have been the S.C. power transformer and the synchronous machine with S.C. coils for both field and armature windings. First studies show that the magnetic induction in such machines remains relatively low so that rare earth permanent magnets (P.M.) with a remanence greater than 1 T (Nd-Fe-B, Sm-Co) are good candidates to create the excitation field. The combination of these two very performant materials opens up new possibilities for large torque motors. Better magnetic properties of the P.M. (intrinsic coercive force above all) at lower temperature than usually and high current density at the armature are two of the key improvments led by this new type of S.C./ P.M. machines. A small amount of soft magnetic materials in such motors may even improve their specific power. First design of a small scale machine is presented.

16:00 ND-07 A STUDY OF HIGH Tc SUPERCONDUCTOR APPLICATION FOR SUPERCONDUCTING GENERATOR
*Naoki Maki, *Kiyoshi Yamaguchi, **Yasuomi Yagi, *Hitachi Research Laboratory, **Hitachi Works, Hitachi Ltd. - High critical temperature superconductors have been discovered recently. The authors have been developing superconducting generator with metallic superconductor used at liquid helium temperature. In this presentation, authors will show the superconducting generator with high Tc superconductor which could be used at liquid nitrogen and room temperature. The features of liquid nitrogen cooled generator and air cooled generator will be compared with liquid helium cooled generator's. Liquid nitrogen cooled generator has features as follows: (1) generator's constants are equal to the helium cooled generator's, (2) the conductor should have ability of allowing current density of 75 A/mm^2 at 4.6 T which is about a half of the request for the liquid helium generator, (3) the efficiency is improved up to 0.03 %. Air cooled generator has features as follows: (1) the weight of the rotor is reduced to 70 %, (2) the efficiency is improved up to 0.02 %, (3) the superconductor is required to have ability of allowing current density of 60 A/mm^2 at 2.9 T. And the problems to be solved will be shown about high Tc superconducting generator.

SEPT. 1 (Fri) Session NE (oral) 14:00-16:20

INSULATORS AND STRUCTURAL MATERIALS-2
Room B

Chairman: S. J. St. Lorant
Stanford Univ.

Cochairman: H. Takahashi
Tohoku Univ.

14:00 NE-01 COMPARISON OF TEST RESULTS WITH ANALYSIS OF GLASS FIBRE REINFORCED EPOXY SHEAR TEST SAMPLES, F. Fardi, N. Mitchell, R. Pochlchen, NET-Team, Garching bei Muenchen, FRG,

In large coils the mechanical strength of the winding is important in maintaining electrical insulation, preventing heat generation through relative movement and giving overall rigidity to support the magnetic forces. The insulation system that gives a good combination of these three factors is glass fibre reinforced epoxy resin with vacuum/pressure impregnation. The usual failure mode of this insulation is in shear, and many tests have been performed at 4 K as part of the establishment of a database for the NET and ITER projects which utilize large superconducting coils. These shear samples have been analyzed with a non-linear elastic-plastic finite element model with the aim of developing a failure criteria for the insulation layer.

14:20 NE-02 DEVELOPMENT OF RADIATION-RESISTANT MAGNETS FOR HIGH INTENSITY BEAM LINES, K.H.Tanaka, M.Takasaki, KEK, National Laboratory for High Energy Physics, Ibaraki, Japan, and K.Kato, TOKIN Corporation, Sendai, Japan

A new counter experimental hall is being constructed at the KEK 12 GeV Proton Synchrotron (KEK-PS). Beam lines in the new experimental hall have been designed to handle beams up to 1 x 10^{13} protons per second in order to accept full proton beams extracted from the upgraded KEK-PS. It is, then, required that the radiation life of beam line components should be over some 10^{8}Gy, at least, a factor of ten more than the life of conventional magnets. We developed a new type of radiation-resistant magnets with use of the polyimide resin pre-impregnated (PRP) glass cloth to insulate the magnet coil. Radiation life of the coil is being tested at the external proton beam line of the KEK-PS and no serious damage was found up to 4 x 10^{8}Gy. All the magnets for the new external proton beam lines are manufactured by using the PRP and no other organic material. The magnets placed just downstream of production targets required higher radiation resistivity up to 10^{11}Gy. For such a special case, we developed also a magnet with completely mineral insulation by using high-alumina cement and asbestos tape in vacuum chamber. This paper describes the present status of the development of radiation-resistant magnets for KEK-PS external beam lines.

14:40 NE-03 EFFECT OF STRAIN RATE ON MECHANICAL PROPERTIES OF COLD -WORKED INCOLOY 908 AT 4 K, I.S. Hwang, M.M. Morra, R.G. Ballinger, M.M. Steeves and M.O. Hoenig, Massachusetts Institute of Technology, Cambridge, MA 02139 - - Incoloy 908 has been developed specifically for use with Nb_3Sn superconductors incorporated in the cable-in-conduit conductor (CICC), of the US-DPC Test Coil. Incoloy 908 is a low coefficient of expansion (COE) superalloy designed for compatibility with the activation requirements of niobium tin superconductors. Mechanical tests have been performed on a series of alloy samples subjected to aging, preceded by 20% cold work. Tensile properties, fatigue crack growth rate and fracture toughness were determined using different strain rates at 298, 77 and 4K. Fatigue crack growth rates were measured over a range of ΔK using unloading compliance techniques. Fracture toughness was determined by the J-integral technique rather than by adiabatic process fracture toughness measurement, in order to avoid the significant metal temperature rise, inherent in the adiabatic deformation process. The paper presents test results and analyses. Selection of appropriate strain rate is discussed for the low temperature testing of structural materials associated with superconducting magnets.

15:00 NE-04 EFFECTS OF STIFFNESS ON SERRATED DEFORMATION AT VERY LOW TEMPERATURES UNDER CONSTANT LOADING RATE CONDITION AND ITS COMPUTER SIMULATION, K.Shibata and K.Fujita, The University of Tokyo, Tokyo, Japan

Almost all matallic materials exhibit serrated stress(or load)-strain(or elongation) curves at very low temperatures. This serrated deformation is generally called as serration. The serrated deformation behavior at constant cross-head velocity has been studied by many workers. However, as for the deformation under constant loading rate condition, only several papers have been published. The objective of the present paper is to investigate the effects of stiffness of machine or machinery structure by using computer simulation. The simulation method was similar to that reported previously by the present authors in the case of constant cross-head velocity condition. It was clarified that the deformation behavior under constant loading rate condition could also be reproduced by the computer simulation. The onset stress of serration was lower under constant loading rate condition than under constant cross-head velocity condition. As machine stiffness was increased, smaller and more frequent serration occurred. In order to find the way to depress the remarkably rapid and large deformation under constant loading rate condition, the effect of back stress from surroundings was investigated by the simulation and it was shown that the degree of the rapid and large deformation was decreased by the back stress which was assumed to be proportional to the amount of specimen deformation.

15:20 NE-05 MECHANICAL PROPERTIES OF SUS304 STAINLESS STEEL UNDER COLD THERMAL CYCLES. Y. Mukai and A. Nishimura. Faculty of Engineering, Osaka University, Osaka, Japan

The thermal strain is considered to be concentrated at the field of temperature distribution or the stress concentration region, such as weldment of welded structures for cryogenic use, during cooling dwon to cryogenic temperature or warming up to room temperature. As this strain cycling due to the cold thermal cycles has a possibility to cause the cold thermal fatigue, it is recognized to be important to clarify the cold thermal cycle properties of the cryogenic structural materials. In this study, the austenite stainless steel, SUS304, which is a very popular material for the cryogenic structural materials, was taken up, and its cold thermal cyclic properties between about 300K and 40K under deformation restraint was investigated. The cold thermal cyclic test was carried out using pipe type specimen and a cold He gas or a warm N_2 gas was run out through the specimen. Number of cooling and warming cycles was 3 or 10 cycles. The degree of thermal strain concentration became large, non-linear behavior (plastic deformation) was recognized by a little decrese of temperature, and a large plastic strain was measured. After 2nd cycle, the stress-strain hysteresis curves were not changed so much, because the driving force of deformation was due to the thermal expansion property of material and the range of cooling or warming temperature. Although the martensite transformation strain caused on cooling process or the austenite transformation strain caused on warming process was not estimated clearly, if these transformation strains were negligible to the total mechanical strain range, it was concluded that the cold thermal cyclic strain would occur the cold thermal fatigue fracture.

15:40 NE-06 DEFORMATION BEHAVIOR OF AUSTENITIC STAINLESS STEELS AT CRYOGENIC TEMPERATURES, T. Ogata, K.Ishikawa, T. Yuri, and O. Umezawa, National Research Institute for Metals, Tsukuba Labs., Ibaraki, Japan

We studied the behavior of austenitic stainless steels to evaluate the accurate properties of structural materials at low temperatures. The materials used in this study are SUS 304L, 310S, and 316LN. We carried out the load- and displacement-contorolled tensile tests, fatigue tests, and creep tests at 293, 77, and 4 K. We also conducted the specimen temperature measurements during tensile and fatigue tests. An abrupt and large discontinuous deformation occurs in load-controlled tensile tests, which differs from the discontinuous deformation obtained from displacement-controlled tests and is significant in 310S steel. This phenomena indicates that if a material at low temperatures is in the freely deforming condition and a deforming force is kept constant during a deformation such as in a magnetic field, it will fail at a much lower stress than the stress obtained in the usual displacement-controlled tensile tests. The temperature rise during the discontinuous deformation was 70-100 K. In fatigue tests, the minimum specimen temperature increased with the increase of testing frequency and strain range, and it exceeded 1 K above a strain rate of 1 %/s. A creep rate of 10^{-10} s^{-1} after 200 hours test at a stress level of the 0.2 % proof stress was detected even at 4 K for the alloy SUS 310S. A creep rate of SUS 304L and 316LN at 4K at the proof stress of each steel became almost zero after tens of hours testing. We attribute the difference of the deformation behavior among the materials mainly to the difference of work-hardening rate.

16:00 NE-07 FATIGUE AND FRACTURE OF Ti ALLOYS AT CRYOGENIC TEMPERATURES, K. Nagai, T. Yuri, O. Umezawa and K.Ishikawa, National Research Institute for Metals, Tsukuba Labs., Tsukuba, Ibaraki, Japan

Titanium(Ti) and its alloys have a high strength-to-weight ratio and a nonmagnetic property, and further Ti alloys have a higher electric resistivity and a smaller thermal conductivity than austenitic stainless steels. However, the cryogenic mechanical data are not much accumulated. In the present study, therefore, tensile properties, Charpy absorbed energy, fracture toughness and fatigue properties were investigated for Ti alloys at cryogenic temperatures. The Ti alloys with reduced content of oxygen and iron showed an excellent combination of high yield strength and high toughness at 4 K. Fracture behavior at cryogenic temperatures is also discussed. Fracture mode transition at lower temperature was observed for higher oxygen CPTi and b.c.c. type Ti alloys. S-N curves of Ti-5Al-2.5Sn and Ti-6Al-4V alloys with reduced oxygen content showed higher fatigue strength than SUS316LN steel.

POST-DEADLINE

PD-01 MAGNETIC SYSTEM OF THE PULSE STRETCHER RING, P.I. Gladkikh, Yu.N. Grigor'ev, S.V. Efimov, A.Yu. Zelinskij, I.M. Karnaukhov, S.G. Kononenko, N.I. Mocheshnikov, A.S. Tarasenko, A.A. Shcherbakov, Kharkov Institute of Physics and Technology, Ukrainian SSR Academy of Sciences, 310108 Kharkov, USSR, M.G. Nagaenko, A.V. Popov, B.V. Rozhdestvenskij, and N.F. Shilkin, D.V. Efremov Scientific Research Institute for Electrophysical Equipment, 188631 Leningrad, USSR

A 3 GeV electron stretcher-storage ring designed at the Kharkov Institute of Physics and Technology is intended for studies in nuclear and elementary particle physics. The magnet lattice is being optimized to produce beams of synchrotron radiation.

Main parameters of the magnetic elements are given along with the analysis of mechanical and alignment tolerances. Beam injection and extraction systems are briefly outlined, the closed orbit correction system is also described.

PD-02 SUPERCONDUCTING SWITCH AND JOINT ON 1 T MRI MAGNET, Min-He Lin, Kejian Corporation Ltd.

Superconducting switch and joint are key parts on superconducting system. A high quality superconducting switch has been developed. It was adopted superconducting magnetic shield technique. So its performance get short sample critical current (242A, at 4.4T). Five superconducting joints have been made by new technique. Their performance are good ($<10^{-10}\Omega$, at 242A, 3.5 T) and three of them get short sample critical current ($<10^{-10}\Omega$, at 242A, 4.4T). The design idea and test result are given.

PD-03 CRITICAL CURRENT MEASUREMENTS OF SUPERCONDUCTING CABLES FOR HERA DIPOLE MAGNETS USING THE FACILITY MA.RI.S.A., P.Fabbricatore, R. Musenich, R.Parodi, R.Vaccarone I.N.F.N., GENOVA, ITALY

The facility MA.RI.S.A., built up during 1986 at the I.N.F.N. laboratory in Genova, was used during last years to measure the critical current of several S/C cables (for HERA dipole magnets) up to 6.4T field at 4.2 k. Since the first measurements, a comparison was made with the results obtained at Brookhaven National Laboratory (BNL) on samples of the same cable. A difference of about 500-600 A corresponding to 8% was found (our measured critical currents were lower than the BNL ones). These results gave impulse to a research aiming to understand the influence of the several parameters involved in the Critical Current Measurement in order to compare results obtained in different sets-up. The experience made during two years of tests is reported. Two parameters are introduced : a) The Effective Critical Field at the cable; b) the effect of field inhomogeneity on the Critical Current degradation.

PD-04 THE HIGH FIELD MAGNETIC DEPENDENCE OF CRITICAL CURRENT DENSITY FOR Ag SHEATHED Bi-Sr-Ca-Cu-O TAPE WIRE AT 4.2K,N.Enomoto, H.Kikuchi, N.Uno, M.Ikeda, The Furukawa Electric Co.,Ltd, Yokohama, Japan, H.Kumakura, K.Togano, National Research Institute for Metals, Tsukuba Laboratories. Ibaraki Japan. K.Watanabe, Institute for Materials Research, Tohoku University Sendai Japan

Measurement of critical current density (Jc) and its dependence on magnetic field in Ag-sheathed superconducting tape wire of Bi-Sr-Ca-Cu-O with the low-Tc phase (85K), of which grain alignment was improved by heat treament, was conducted at 4.2K as follows: In case of magnetic field applied in direction parallel to the wide plane of the wire specimen, the Jc of it was 1.2×10^5 A/cm^2 at 1T and 5×10^4 A/cm^2 at 10T, which value was almost constant up to 23T. The degree of crystal orientation by XRD (F)was 90% for this specimen. Then, as decreasing F value from 90%, the Jc under magnetic field was decreased. The pinning force (Fp) of the highly oriented tape wire was calculated about 1×10^{10} N/m^3 at 20T. This value exceeds the one of conventional low Tc superconductors. High-field magnet designing will be discussed.

PD-05 TOWARDS THE REALIZATION OF TWO 1.2 TESLA SUPERCONDUCTING SOLENOIDS FOR PARTICLE PHYSICS EXPERIMENTS, D. E. Baynham and P. T. M. Clee, Rutherford Appleton Laboratory, England.

Superconducting solenoids are required to produce a magnetic field of 1.2 Tesla in a room temperature volume of 145m^3 for the DELPHI particle physics experiment on LEP at CERN and for the H1 experiment on HERA at DESY. The large solenoids which are in the region of 5-6m diameter and 5-7m long, were constructed with aluminum clad Nb-Ti conductor, wound on the inside of a liquid helium cooled support cylinder. The coils are indirectly cooled with 2 phase liquid helium and suspended within an 80K gas cooled radiation shield inside a stainless steel vacuum vessel. The coils have a stored energy > 100 MJ when powered at 5000A. The paper covers aspects of the construction, installation and test of the two solenoids.

- END -

22161
45
NTIS
ATTN: PROCESS 103
5285 PORT ROYAL RD
SPRINGFIELD, VA 22161

This is a U.S. Government publication. Its contents in no way represent the policies, views, or attitudes of the U.S. Government. Users of this publication may cite FBIS or JPRS provided they do so in a manner clearly identifying them as the secondary source.

Foreign Broadcast Information Service (FBIS) and Joint Publications Research Service (JPRS) publications contain political, economic, military, and sociological news, commentary, and other information, as well as scientific and technical data and reports. All information has been obtained from foreign radio and television broadcasts, news agency transmissions, newspapers, books, and periodicals. Items generally are processed from the first or best available source; it should not be inferred that they have been disseminated only in the medium, in the language, or to the area indicated. Items from foreign language sources are translated; those from English-language sources are transcribed, with personal and place names rendered in accordance with FBIS transliteration style.

Headlines, editorial reports, and material enclosed in brackets [ ] are supplied by FBIS/JPRS. Processing indicators such as [Text] or [Excerpts] in the first line of each item indicate how the information was processed from the original. Unfamiliar names rendered phonetically are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear from the original source but have been supplied as appropriate to the context. Other unattributed parenthetical notes within the body of an item originate with the source. Times within items are as given by the source. Passages in boldface or italics are as published.

SUBSCRIPTION/PROCUREMENT INFORMATION

The FBIS DAILY REPORT contains current news and information and is published Monday through Friday in eight volumes: China, East Europe, Soviet Union, East Asia, Near East & South Asia, Sub-Saharan Africa, Latin America, and West Europe. Supplements to the DAILY REPORTs may also be available periodically and will be distributed to regular DAILY REPORT subscribers. JPRS publications, which include approximately 50 regional, worldwide, and topical reports, generally contain less time-sensitive information and are published periodically.

Current DAILY REPORTs and JPRS publications are listed in *Government Reports Announcements* issued semimonthly by the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161 and the *Monthly Catalog of U.S. Government Publications* issued by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

The public may subscribe to either hardcover or microfiche versions of the DAILY REPORTs and JPRS publications through NTIS at the above address or by calling (703) 487-4630. Subscription rates will be provided by NTIS upon request. Subscriptions are available outside the United States from NTIS or appointed foreign dealers. New subscribers should expect a 30-day delay in receipt of the first issue.

U.S. Government offices may obtain subscriptions to the DAILY REPORTs or JPRS publications (hardcover or microfiche) at no charge through their sponsoring organizations. For additional information or assistance, call FBIS, (202) 338-6735,or write to P.O. Box 2604, Washington, D.C. 20013. Department of Defense consumers are required to submit requests through appropriate command validation channels to DIA, RTS-2C, Washington, D.C. 20301. (Telephone: (202) 373-3771, Autovon: 243-3771.)

Back issues or single copies of the DAILY REPORTs and JPRS publications are not available. Both the DAILY REPORTs and the JPRS publications are on file for public reference at the Library of Congress and at many Federal Depository Libraries. Reference copies may also be seen at many public and university libraries throughout the United States.